

From Evaluation to Design: A User-Centered Approach to Production Machine Interfaces

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MASTER THESIS



From Evaluation to Design: A User-Centered Approach to Production Machine Interfaces

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Abstract

This master thesis focused on evaluating and designing the user interface of a camera production machine used in an industrial manufacturing environment. The project was conducted in collaboration with a global technology company and aimed to improve usability, clarity and operational support through a user-centered design approach. The work began with a comprehensive pre-study of the existing interface including heuristic evaluation, usability testing, interviews, and surveys, to identify strengths, limitations, and user needs across different roles. Based on the findings from the pre-study, an iterative design process was applied, involving ideation, low-fidelity prototyping, and high-fidelity refinement. Design decisions were grounded in established usability heuristics, industry standards, and user feedback. Two iterations of Lo-Fi prototypes were developed and evaluated to explore alternative layouts, interaction flows, and information structures, followed by a Hi-Fi prototype that consolidated and refined the most effective solutions. Multiple rounds of usability testing were conducted throughout the process to guide design iterations and validate improvements. The final interface introduced clearer process visualization, including a newly introduced progress overview that provides continuous insight into unit status. In addition, error and alarm handling are presented in a more structured manner, and overall visual clutter has been reduced. Quantitative results from the System Usability Scale (SUS) evaluations indicate a substantial improvement in perceived usability compared to the existing system. While the re-designed interface demonstrates significant usability gains, the study also highlights challenges related to accommodating users with varying levels of expertise and differing operational needs. The resulting proof-of-concept user interface provides a validated foundation for future development of production machine interfaces.

Keywords: Human–Machine Interface (HMI), User-Centered Design (UCD), Usability Testing, User Experience (UX), Production System

Sammanfattning

Detta examensarbete fokuserar på att utvärdera och designa användargränssnittet för en kameratillverkningsmaskin som används i en industriell produktionsmiljö. Arbetet genomfördes i samarbete med ett globalt teknikföretag och syftade till att förbättra användbarhet, tydlighet och operativt stöd genom en användarcentrerad designprocess. Arbetet inleddes med en omfattande förstudie av det befintliga gränssnittet, inklusive heuristisk utvärdering, användbarhetstester, intervjuer och en enkät, för att identifiera styrkor, begränsningar och användarbehov hos olika roller. Utifrån resultaten från förstudien tillämpades en iterativ designprocess som inkluderade idégenerering, low-fidelity-prototyper samt vidareutveckling till en high-fidelity-prototyp. Designbeslut fattades med stöd i etablerade användbarhetsriktlinjer, industristandarder och användarfeedback. Två iterationer av Lo-Fi-prototyper utvecklades och utvärderades för att undersöka alternativa layouter, interaktionsflöden och informationsstrukturer, följt av en Hi-Fi-prototyp som sammanförde och förfinade de mest effektiva lösningarna. Flera omgångar av användbarhetstester genomfördes under processen för att vägleda designiterationer och validera förbättringar. Det slutliga gränssnittet introducerar en tydligare visualisering av processen, inklusive en ny processöversikt som ger kontinuerlig insyn i enheternas status och arbetsflödets förlopp. Dessutom presenteras fel- och larminformation på ett mer strukturerat sätt samtidigt som den visuella komplexiteten har reducerats. Kvantitativa resultat från System Usability Scale-utvärderingar (SUS) visar en avsevärd förbättring av upplevd användbarhet jämfört med det befintliga systemet. Även om det omdesignade gränssnittet uppvisar tydliga användbarhetsförbättringar, påvisar studien även utmaningar kopplade till att tillgodose användare med varierande erfarenhetsnivåer och olika operativa behov. Den framtagna gränssnittslösningen utgör ett validerat proof-of-concept och erbjuder en stabil grund för framtida utveckling av användargränssnitt för produktionsmaskiner.

Nyckelord: Människa–maskin-gränssnitt, Användarcentrerad design, Användbarhetstestning, Användarupplevelse, Produktionssystem

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1 Introduction

This chapter introduces the background and context of the master thesis. It describes the motivation behind the project and provides a brief description of the company. The chapter then presents the purpose and research questions, which guide the project as a whole. In addition, the chapter includes sections on the project's relevance to global sustainability goals, ethical considerations, and an overview of related works.

1.1 Background

Industrial machines are becoming increasingly automated. Despite this, human operators remain a critical factor of manufacturing systems [15]. Product quality and factory efficiency are strongly dependent on human performance, as operators interact with machines in various ways, such as supervising processes, executing tasks, loading and unloading equipment, and engaging with machine interfaces.

As a result, the quality of the interface plays a significant role in overall system performance. Poorly designed interfaces can reduce the efficiency of these interactions and slow down production processes. Conversely, while operator safety is primarily ensured by the physical system, a well-designed Human-Machine Interface (HMI) can significantly improve production efficiency by enabling faster and more accurate interactions.

As technological complexity increases, HMIs have become more advanced and play an increasingly important role. Therefore, their design and usability are crucial for supporting efficient, reliable and user-friendly interaction, reducing cognitive load, and minimizing the risk of operator error [15].

HMIs are used in various types of machines and systems, such as industrial control panels, packaging and assembly machines, Computer Numerical Control machines, and camera production systems [1]. Camera production systems are used by manufacturing companies, including the company where this thesis was conducted.

1.2 About the Company

This thesis was carried out in collaboration with a global technology company specializing in network-based imaging devices and related security solutions. For confidentiality, the organization will be referred to throughout this report as “the company”. The company develops a broad range of hardware and software solutions used across diverse industries including imaging systems, analytics tools, and supporting infrastructure.

While product development is primarily conducted at the company’s main research and development site, large-scale manufacturing is conducted by partner manufacturing sites worldwide. To ensure consistent production quality, the company designs specialized assembly and testing equipment in-house. These systems are deployed at partner manufacturing sites and form the technological environment studied in this thesis.

1.2.1 Camera Production System

The current interface for the camera production system is functional but highly technical and visually outdated. When initially developed, the interface was designed primarily around system functions rather than following a user-centered design philosophy. This has resulted in an interface that presents a large amount of technical information, as well as numerous pop-ups to communicate system states and required actions. A brief overview of the existing interface is shown in Figure 1.1, while a detailed description is provided in Section 3.1.

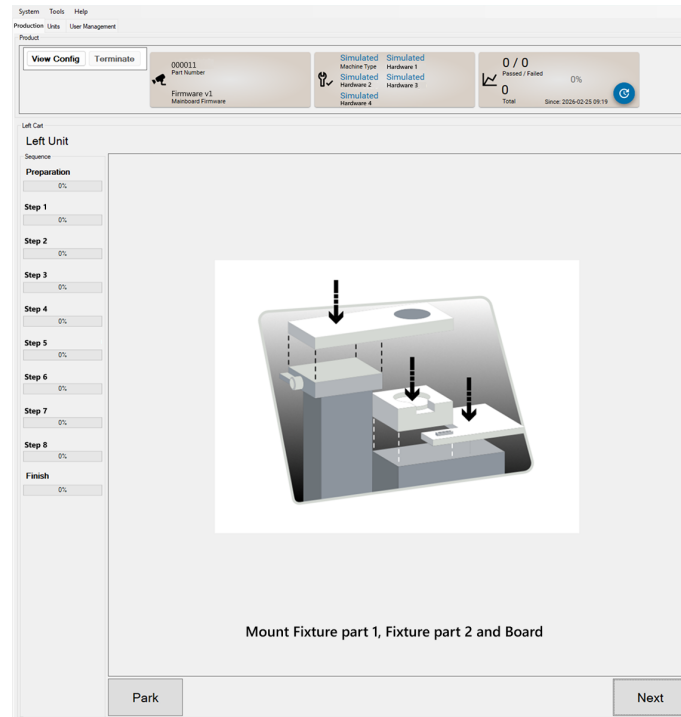


Figure 1.1 Example of the current camera production system interface

1.3 Purpose and Research Questions

The purpose of this master thesis is to develop a proof-of-concept prototype for a new user interface design for a future, more complex, production system that is currently under development. This work includes analysing the existing interface of the camera production system to identify strengths, limitations and user needs, which serve as the foundation for designing an improved interface prototype suited to the requirements of the new system. The research questions are as follows:

- RQ1: What user needs and operational requirements should guide the design of a proof-of-concept interface for the new camera production system?
- RQ2: What design improvements and alterations can make the new user interface more intuitive and efficient to use?
- RQ3: How do users perceive the created user interface prototype compared to the existing camera production system interface?

1.4 Global Sustainability Goals

The Sustainable Development Goals (SDGs) established by the United Nations consist of 17 goals aimed at advancing various aspects of global sustainable development. They are included in Agenda 2030, which was endorsed in 2015 by all United Nations member states [18]. This project contributes primarily to SDG 8, Decent Work and Economic Growth, by improving the usability and operational reliability of industrial machine interfaces. A clearer and more intuitive interface reduces operational errors, lowers cognitive demands and enhances worker well-being which in turn supports more efficient and sustainable industrial workflows. The redesign also aligns with SDG 9, Industry, Innovation and Infrastructure, as it promotes user-centered interaction design within industrial systems. By updating outdated interfaces with contemporary User Experience (UX) practices, the project strengthens digital infrastructure and supports improved interaction quality in manufacturing environments. Furthermore, this work indirectly contributes to SDG 4, Quality Education, by improving the learnability of the machine interface. Using intuitive interaction patterns reduce training time and support continuous skill development among operators. Together, these contributions demonstrate how improved user interfaces for human-machine interaction can advance multiple sustainability goals in industrial settings. The relevant SDGs can be seen below in Figure 1.2.



Figure 1.2 UN Sustainable Development Goals addressed in this work

1.5 Ethical Considerations

When designing an HMI for industrial use, it is essential to consider the users, their work environment, and their varying levels of technical proficiency [13]. A poorly designed HMI can increase cognitive load, create safety risks, and disadvantage users who are unfamiliar with digital systems. Therefore, a user-centered design process is crucial to ensure that the views of various users are taken into account so that the system aligns with real operational conditions and user needs.

Another ethical consideration is the linguistic diversity among operators. Industrial workplaces often include staff who may not be fluent in English, even though the interface is. Relying solely on English can lead to misunderstandings and safety risks. To reduce this, the HMI should use clear icons, avoid unnecessarily technical terminology, and ideally support multiple languages to ensure all users can interpret critical information.

1.6 Related Work

In industrial settings, the design of user interfaces has historically received less attention than the underlying technical systems, which often result in interfaces that do not fully support operator understanding or task requirements. To address these challenges, Kant et al. [11], examines the foundational problems in Human-Machine Interface (HMI) design for efficient manufacturing. The authors further emphasize the importance of human-centered design, operator experience, and meaningful information representations.

Additionally, the study demonstrates how a structured design process can bridge gaps between technical system requirements and operator needs [11]. The described approach shows the value of grounding interface decisions in real operational contexts, ensuring that complexity is translated into clear, actionable information that supports more reliable operations and minimizes the likelihood of operator error. This perspective further underscores why emerging production systems benefit from iterative design cycles that incorporate user feedback and contextual analysis.

While Kant et al. [11] primarily focus on the human-centered aspects of HMI design, Malyi and Bryksin [12], focuses on structural and organizational challenges affecting HMI design across industrial systems. In particular, it addresses the lack of industrial standardization for HMIs, which results in inconsistencies among HMI applications. While a standard for code development exists (IEC 61131-3:2013), which provides a detailed and uniform structure for writing automation control programming, no equivalent level of guidance has been established for the visualization development process. This absence of standardization leads to inefficiencies in both development and operations, as well as poor user experience and increased risk of operator error.

To address this issue, the article suggests a layered design system architecture structured as a five-level framework [12]. The key elements of this architecture are Design Foundations, Brand Identity, Design Tokens, UI Kit, UI Components, and Design Library. The framework aims to ensure a consistent user experience and visual style across diverse applications. In addition to usability benefits, the article emphasizes the importance of a unified HMI design system, highlighting reductions in development cost and time by reusing interface components and solutions, as well as im-

provements in operational efficiency by minimizing equipment downtime, reducing operator training time, and lowering production risks related to operator error and health.

The two articles provide valuable foundational support for this thesis. Kant et Al. [11] adopt a human-centered approach that focuses on operator cognition and contextual understanding. This article will be beneficial during the evaluation of the existing system by supporting the identification of issues related to operator experience, thereby helping to gather user-centered requirements. In contrast, Malyi and Bryksin [12] address the lack of standardization in HMI design and propose a layered design system aimed at ensuring consistency and reusability. Their framework will be useful during the design process of the new system.

2 Theory & Methodology

This chapter introduces the theoretical principles and methodological processes that guide the study. It explains the guidelines, design activities, and research methods that structure the development and analysis of the work.

2.1 Industry Guidelines

This section outlines the industry guidelines that guide the creation of reliable and user-centered Human-Machine Interface (HMI) systems. It covers core HMI design principles and the standards that support consistency, clarity, and safe interaction in industrial environments.

2.1.1 Human-Machine Interface Systems

An HMI is a digital interface that enables operators to monitor, interact with, and control automated systems through visual displays and touch inputs in real time [9]. As production systems grow more complex, the importance of clear, standardized, and operator-focused display design increases significantly. This need for clarity and efficiency has led to the development of high-performance HMI principles.

A high-performance HMI is designed to support operators in making fast and correct decisions with minimal cognitive load [2]. In modern automated manufacturing systems, the HMI is the primary point of interaction between human operators and machinery which makes its design crucial for safe and efficient operations. High-performance HMI philosophy emphasizes situational awareness, clarity, and consistency. Instead of relying on visually attractive but distracting elements, such as 3D graphics, bright animations, or decorative icons, the focus is placed on presenting information in a way that enhances safety, supports quick interpretation and reduces the risk of operator error [9]. This approach stands in contrast to traditional schematic-style displays, which often attempted to visually replicate the physical system and therefore introduced unnecessary clutter and slower operator response.

Effective HMI design requires careful attention to layout, colour usage, graphics, text clarity, alarm handling and navigation [9]. Clear layouts, minimalistic graphics, standardized colours, readable data and a logical page hierarchy help operators interpret information quickly, reduce cognitive load and minimize the risk of errors.

2.1.2 International Organization for Standardization

ISO (the International Organization for Standardization) develops global standards used in various industries to provide consistent guidelines. One such standard used in this thesis is Interaction Principles: EN ISO 9241-110:2020, which addresses the ergonomics of human-machine interaction, with a particular focus on interaction principles and general design recommendations [10]. The standard covers areas such as learnability, user engagement and use error robustness, among others. These guidelines can be applied during both the design and evaluation of interactive systems, thus creating a usable and accessible interface that contributes to a positive user experience. It should be noted that the document does not offer concrete standards of how to develop and implement HMIs, instead it offers principles and guidance of what good interaction should achieve.

While ISO standards provide high-level interaction principles, they lack concrete guidance for industrial HMI visualization. This leads to inconsistent UI design and highlights the need for structured, user-centered approaches in industrial contexts [12].

2.2 Usability & Design Guidelines

This section introduces key principles that support the analysis and creation of usable and effective interactive systems. It outlines the foundations of user-centered design, presents Nielsen's usability heuristics and their role in heuristic evaluation and describes the core activities that guide the interaction design process.

2.2.1 User-Centered Design

User-centered design (UCD) is a design approach that places the needs, goals, and context of real users at the center of the development process [17]. Instead of letting the available technology dictate the solution, the UCD philosophy is grounded in understanding who the users are, how they work, and what they aim to accomplish. To support this way of working, three guiding principles help structure and direct the design process.

The first is an early focus on users and their tasks, meaning that researchers must study the behaviour of users, their characteristics, and work practices before shaping design decisions [17]. The second is empirical measurement, where user reactions and performance are observed, recorded, and evaluated throughout the development process, from initial drafts to interactive prototypes. The third principle is iterative design, emphasizing that insights from usability testing should result in successive iterations that gradually enhance the solution.

Together, these principles highlight the importance of grounding design choices in user needs and validating them through iterative testing, ensuring that the final product effectively supports users in their work [17].

2.2.2 Usability Heuristics for User Interface Design

Nielsen proposed a set of ten usability heuristics in 1994 [14] aimed at guiding the development of well-functioning and user-friendly systems. Rather than offering concrete design instructions, these heuristics serve as rules of thumb that inform design decisions. The ten heuristics are:

1. **Visibility of System Status:** The system should clearly show users what is happening at all times. Quick and clear feedback helps users understand their actions and know what to do next.
2. **Match Between the System and the Real World:** The design should use words and ideas that feel familiar to users and follow real-world conventions. When interfaces match how people naturally think and act, they become easier to understand and use.
3. **User Control and Freedom:** Clear ways to cancel or back out help users recover from mistakes and feel confident while using the system.
4. **Consistency and Standards:** Designs should follow common conventions and use consistent terms and patterns, both within the product as well as across similar products. This overall consistency helps users learn the interface more easily.
5. **Error Prevention:** Interfaces should reduce the chance of errors by avoiding error-prone conditions and confirming important actions, helping users avoid both slips and mistakes.
6. **Recognition Rather than Recall:** The user interaction should minimize memory load by keeping relevant information visible, helping users recognize actions instead of recalling them.
7. **Flexibility and Efficiency of Use:** The user interaction should allow efficient shortcuts and customization so both new and expert users can work in the way that suits them.

8. **Aesthetic and Minimalist Design:** The interface should focus on essential content and avoid unnecessary elements that distract from the key information. A clean, minimal layout makes important information easier to notice and understand.
9. **Help Users Recognize, Diagnose, and Recover from Errors:** The interface should show clear and easy to understand error messages with guidance on how to fix the problem, supported by visuals that make them stand out.
10. **Help and Documentation:** Good design should work without explanation, but clear help and documentation must be available when users need extra support. This guidance should be easy to find, concise, and offer simple, concrete steps.

2.2.3 Heuristic evaluation

A heuristic evaluation is conducted by systematically reviewing an interface against a predefined set of rules, which is typically Nielsen's 10 usability heuristics [14]. This method is applied in order to gain an understanding of where the design may fall short in supporting users and detect any glaring usability issues. The actual process begins with preparing the evaluators, defining the scope of the evaluation and choosing a documentation format. Each evaluator then inspects the interface independently, first familiarizing themselves with the product and then identifying potential heuristic violations. After all the evaluations are completed, the team consolidates findings by grouping similar issues and discussing severity, patterns and priorities. While heuristic evaluations provide valuable insights, they cannot replace the need for user research.

2.2.4 Four Basic Activities of Interaction Design

The four basic activities of interaction design were formed in order to create a user-centered design [17]. These iterative activities are supposed to work together as a lifecycle model and do not need to be conducted in a strict sequence, as seen in Figure 2.1. The four activities are:

Discovering Requirements

This activity focuses on identifying the requirements and needs of the targeted users in order to define what should be developed. These insights are gathered through data collection and analysis.

Designing Alternatives

This activity builds upon the collected requirements and focuses on exploring design approaches, as well as designing different alternatives that align with the user needs.

Prototyping

Prototyping focuses on visualizing the designs by making them interactable. Prototyping is an effective way to evaluate the functionality, behaviour, and appearance of the design.

Evaluating

The evaluation process focuses on measuring the usability benchmarks of the prototype, in order to confirm and verify that the product meets its requirements and usability standards.

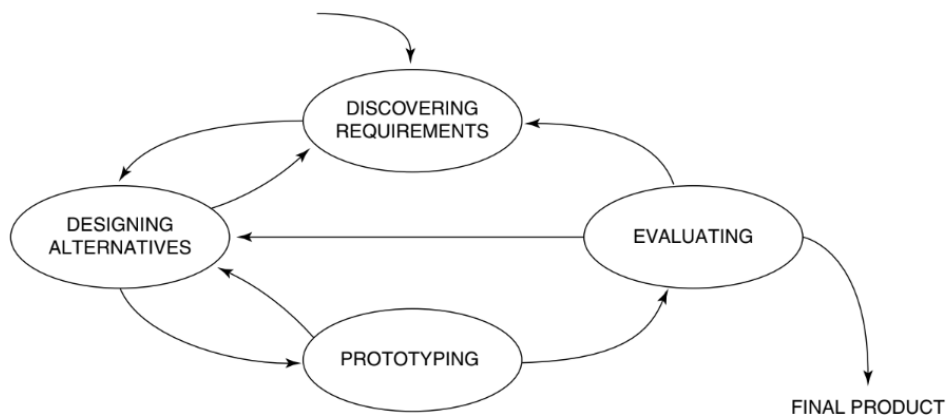


Figure 2.1 The four activities of interaction design as a lifecycle model

2.3 Ideation

Ideation refers to the creative process of generating ideas and solutions [6]. The aim is to produce a wide range of ideas, which can later be refined to identify the most practical and effective solutions.

2.3.1 Brainstorming

Brainstorming is an activity used to generate, refine, and develop ideas for gathering requirements or creating alternative designs [17]. Different formats exist to support creativity and collaborative thinking, allowing participants to contribute individually or collectively in structured or free-form ways. For successful brainstorming, it is important to remain open to all ideas and to keep the user in mind.

2.4 Prototyping

Prototyping is a central activity in the development phase of the design process, supporting the iterative cycle of designing, evaluating, and refining concepts [17]. A prototype is a concrete representation of an idea which enables designers to explore how a product might look, behave or support particular tasks. Prototypes are used to communicate design intentions, compare alternative solutions, clarify requirements, as well as test usability at different stages of the process. These can take many forms and be introduced at various points in the design process. They may range from early paper sketches and physical mock-ups to more advanced interactive digital models, each highlighting certain design aspects while simplifying others.

2.4.1 Lo-Fi

Early on in a project, low-fidelity prototypes, such as sketches, storyboards, and paper interfaces, enable rapid exploration and quick iteration [17]. Since they are inexpensive, easy to modify, and require minimal technical skill, they are well suited for uncovering conceptual issues and testing early ideas without committing to detailed design choices early. This makes them effective tools for shaping the initial direction of a design.

2.4.2 Hi-Fi

As the design progresses, high-fidelity prototypes offer a more realistic depiction of the product in terms of appearance, interaction, and functionality [17]. These versions allow designers to evaluate detailed behaviour, implementation feasibility, and the performance in context. However, they require more time and resources to create and are typically harder to modify, which makes them more suitable for later stages when key design directions are more clear.

2.5 Data Gathering

Data gathering refers to the process of collecting data using different techniques and is a central step in the design process, both for finding requirements and for evaluating design solutions [17]. The data gathered is essential for understanding the user, as well as the design. Such data is typically divided into quantitative and qualitative forms.

Quantitative data consists of numerical measures suitable for aggregation, comparison to benchmarks, and statistical analysis. Examples include completion rate, time on task, and error rate. Qualitative data, on the other hand, consists of descriptive findings that explain user behaviours and reveal underlying mental models. This type of data may include user comments and quotes, body language, and observed strategies. This section presents methods and techniques used to collect both quantitative and qualitative data.

2.5.1 Triangulation

Triangulation refers to the use of at least two different approaches when investigating a phenomenon [17]. The use of multiple data gathering methods enables researchers to obtain richer insights through different perspectives and to make up for the limitations of individual methods [4].

2.5.2 Interviews

Interviews are one of the most commonly used methods for gathering data in interaction design and user-centred research. They allow researchers to explore users' needs, motivations, and experiences in depth, often revealing insights that are difficult to capture through observation or quantitative methods alone [17]. Interview types differ in their level of structure, ranging from unstructured to completely fixed. Unstructured interviews are open and conversational, providing broad exploratory insights but producing less consistent data across participants. Meanwhile, structured

interviews use predefined, closed questions in a fixed order, supporting easy comparison but limiting depth. Semi-structured interviews strike a balance between the two, combining prepared questions with flexible exploring. This format balances consistency with the ability to uncover rich and unexpected insights. Focus groups gather multiple participants for a guided discussion and are useful for exploring shared perspectives, though group influence may shape individual responses.

Selecting an appropriate interview type depends on what the study aims to uncover, the level of detail required, and where the project is in the design cycle. Furthermore, planning an interview involves defining clear goals, preparing appropriate questions, arranging practical logistics, ensuring consent and ethical considerations, and following a structured flow from introduction to closing [17].

2.5.3 Surveys

Surveys are an efficient way to gather data from a large sample of people in a relatively short time [16]. Although they may not provide as in-depth answers as other data gathering methods, they allow for better generalization to a broader population. Surveys can include quantitative questions, such as rating scales and checkboxes, as well as qualitative open-ended questions in the form of free-text responses. They can be conducted online, making them more convenient and accessible to most participants. A survey can be used at any time throughout the design process; however, it can be most beneficial in the early stages for gathering requirements and understanding the user.

2.5.4 Usability Testing

Usability testing is a structured method for evaluating how effectively users can perform representative tasks using a system or product [16]. It examines how well the product meets defined usability goals. The process involves defining clear test objectives, preparing realistic task scenarios, as well as observing participants as they attempt to achieve specific goals. Throughout the session, both quantitative data, such as task completion rates and error frequencies, and qualitative data, such as comments and observed frustrations or delights, are recorded to identify design issues. Several factors influence how many participants are involved in a usability test, including the required level of confidence in results, available resources, participant availability, and the duration of each session.

A central component of usability testing is the development of a detailed test plan, which acts as the blueprint for the entire process [16]. It specifies the purpose of the test, the research questions, participant characteristics, task list, and procedural guidelines. Based on the test plan, task lists are created to describe the activities participants must complete, along with their success criteria and relevant contextual

information. Scenarios are written to provide background and purpose for each task without revealing the correct steps, allowing evaluators to observe how users naturally navigate the system. This structured approach ensures that findings are reliable, repeatable, and directly tied to improving the user experience of the product.

2.5.4.1 Think Aloud

The “Think aloud” protocol is a common usability evaluation technique in which participants are asked to verbalize their thoughts, intentions, and decision-making processes while completing tasks [17]. This method lets observers capture what users struggle with, as well as their strategy to overcome it in real time. By expressing what they are looking for and why they take certain actions, evaluators gain direct insight into the users’ interpretations of the interface and the challenges they encounter [16]. A limitation of the method is that some participants find speaking their thoughts aloud unnatural, which can limit what they say or affect their behaviour with the system.

2.5.5 Pilot Study

A pilot study is a preliminary test at a smaller scale conducted to evaluate the feasibility of the proposed research design before the main study [17]. The goal is to help identify unclear instructions, technical issues, or methodological weaknesses. This allows researchers to refine procedures, improve data quality and prevent costly errors before full-scale data collection. Commonly, colleagues are often used for piloting and pilot participants cannot join the main study.

2.5.6 System Usability Scale

The System Usability Scale (SUS) is a widely used and lightweight questionnaire designed to provide a quick and reliable measure of a system’s overall usability [3]. It consists of ten statements rated on a five-point Likert scale, alternating between positive and negative wording to reduce response bias. SUS produces a single score from 0 to 100 that reflects users’ subjective perception of how usable a system is. Aspects covered include complexity, confidence, and the need for support. SUS is valuable since it is easy to administer, requires little time from participants, and works across a wide range of technologies [3]. The SUS score is calculated by converting each answer to a 0–4 value (using different formulas for positive and negative items), adding them up, and multiplying by 2.5 for a final score from 0 to 100. A commonly used benchmark is that a score of around 68 represents average usability, meaning scores at or above this level are generally considered positive [3].

2.6 Data Analysis

Effective data analysis is essential for transforming raw findings into meaningful design insights. This section introduces affinity diagramming as a technique for organizing and interpreting qualitative data, as well as personas, which help bring user needs and goals into focus.

2.6.1 Affinity Diagram

Affinity diagramming is a technique used to organize and categorize data into clusters to identify distinct themes [17]. Affinity diagrams can be conducted digitally or with physical sticky notes on a board, and are applicable at any stage of the design process. The affinity diagram is an effective way to explore collected data and reveal patterns and themes, which can later be structured and prioritized into a hierarchy.

2.6.2 Personas

One technique used to bring requirements to life is the creation of personas. Personas are composites of multiple individuals involved in the data gathering process, putting a face to abstract information about different target groups [17]. Each persona typically includes elements such as a name, picture, demographic data, and lifestyle. However, the most crucial factor that differs them is the persona's goal. This technique is valuable for designers, as it can be used to support design decisions by helping them understand whether a solution is suitable or potentially a hindrance, while also serving as a reminder that the product will be used by real people [17].

2.7 Project Tools

This section introduces the digital tools used throughout the design project. These tools supported different phases of the process, including user research, prototyping, and analysis, and enabled efficient teamwork and documentation across the project lifecycle.

2.7.1 Condens

Condens is a qualitative user research repository and analysis tool designed to help researchers store, analyse, and share customer data in a structured and efficient way [5]. By collecting research data in a single hub, it allows researchers to highlight, tag, and connect insights across multiple sessions, while also supporting different analysis techniques such as affinity diagramming directly within a project. Condens also helps maintain participant anonymity by enabling features such as face blurring and voice alteration, and it additionally provides automated transcription and transcript translation to support multilingual analysis within the platform.

2.7.2 Figma

Figma is a cloud-based design and collaboration tool used for creating user interfaces, visual designs, and interactive prototypes [8]. It allows designers and developers to work together in real time, share design systems, and iterate quickly. Figma supports the creation of clickable prototypes with transitions and animations that simulate real user interactions and flows, enabling usability testing and early validation of design concepts before development.

3 Pre-study

This chapter presents the pre-study conducted to understand the interface of the current camera production system and its users. It includes an overview of the existing interface, results from usability testing, an interview, and a survey, as well as insights from a heuristic evaluation. Relevant ISO usability principles and user personas are also introduced. Together, these activities highlight key usability challenges and user needs that inform the key takeaways and guide the development of the new interface concept.

3.1 Current Camera Production System Interface

The interface examined in this project refers to the HMI used by operators during assembly and testing of the camera production machine. The physical machine is an industrial workstation measuring approximately one and a half meters in height, one meter in width and one meter in depth, as shown in Figure 3.1. In the central opening, the operator mounts various components for the machine to perform the assembly process. The HMI is displayed on a 24-inch touch screen positioned above this opening at a comfortable viewing height, serving as the operator's primary interaction point.



Figure 3.1 Existing physical camera production machine

The touch display serves as the operator's primary interaction point and presents the interface layout shown in Figure 3.2 and enlarged in Figure A.1. Along the top left of the screen are typical menu tabs seen in most applications namely "System", "Tools", and "Help", followed by the machine-specific tabs "Production", "Units", and "User Management". This project focuses on the Production tab as it contains the workflow and controls directly involved in the camera assembly process. Within this view, the "View Config" button allows operators to inspect all current machine configurations while the "Terminate" button serves as an emergency stop that can be activated once the machine is running. To initiate operation of the machine, the operator selects "Start Machine", located in the upper right corner of the screen.

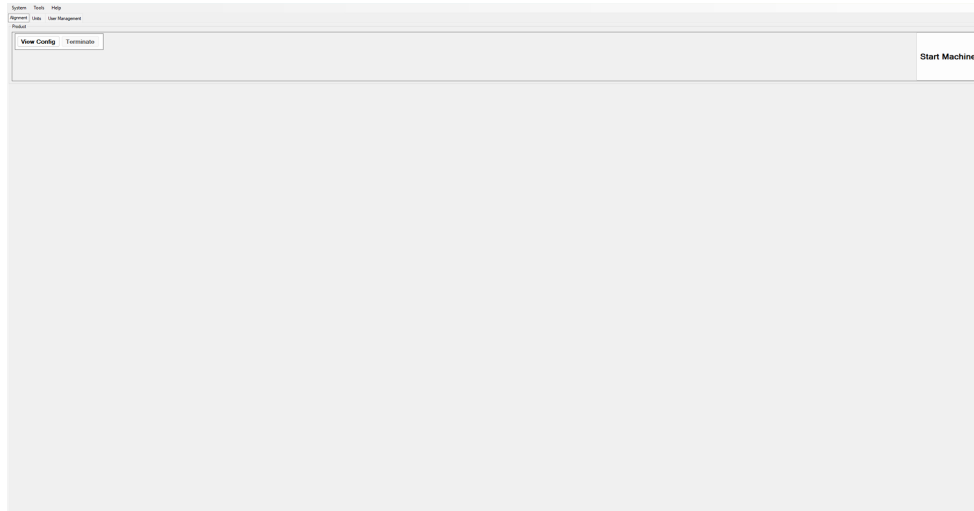


Figure 3.2 Start screen of the camera production system interface

Before the machine becomes fully activated, the operator is guided to select a product, as shown in Figure 3.3. The product selection appears in a pop-up window displayed on top of the start screen. This pop-up contains a product grid that lists the available product types for the upcoming process. However, products only appear in the grid once they have been added from an additional pop-up containing a complete list of all available products, shown in Figure 3.5 and enlarged in Figure A.2. This list is accessed by selecting the “File” button located in the upper-left corner of the product grid pop-up named “Select Product”. An instructional prompt is shown when the product grid contains no items, but it is not present once products have been added. Figure 3.4 displays both versions of the interface.

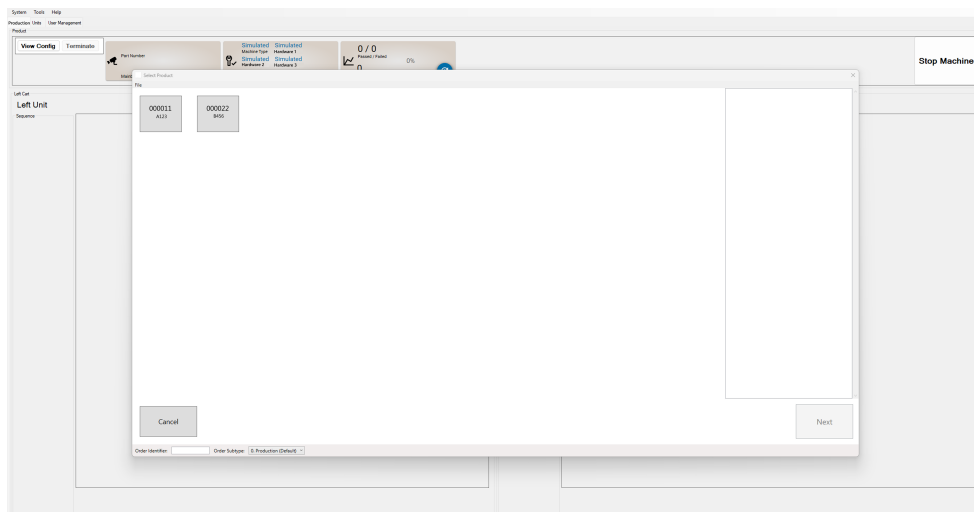


Figure 3.3 Product grid displayed during product selection

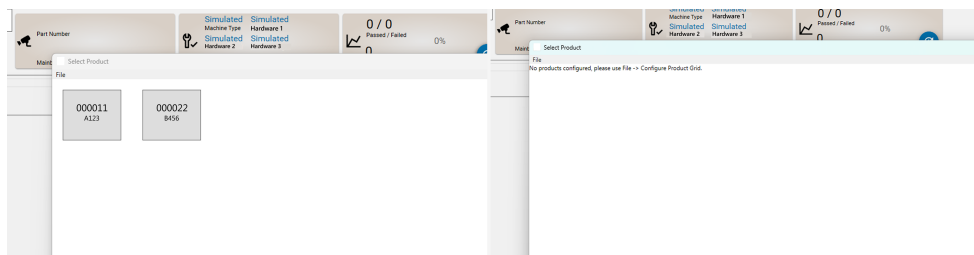


Figure 3.4 Product grid with and without added products

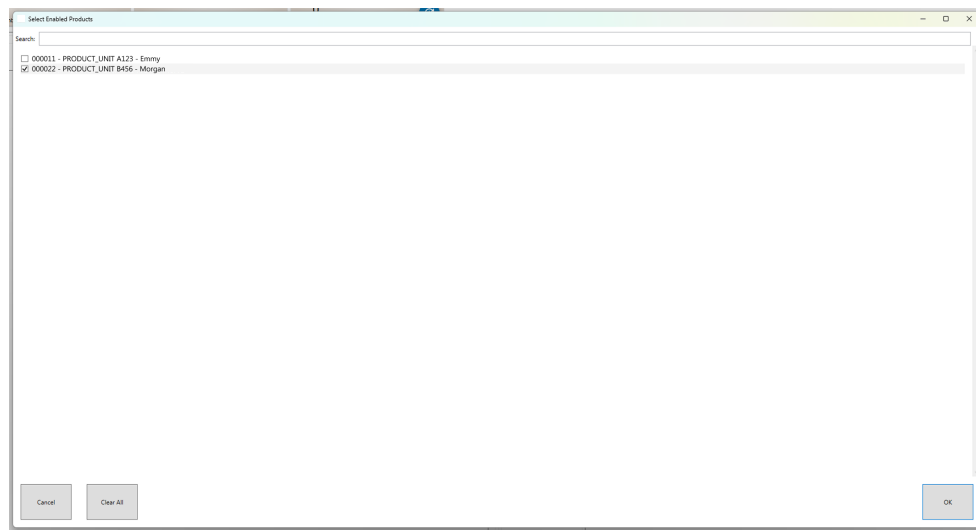


Figure 3.5 Pop-up containing the complete list of available products

By selecting a product in the product grid, a panel appears on the right side of the pop-up. This panel, referred to in this thesis as the Product Information Field, presents all relevant information about the selected product, including ID numbers and associated images, as shown in Figure 3.6 and enlarged in A.3. Once the desired product has been chosen, pressing “Next” initiates the activation of the machine.

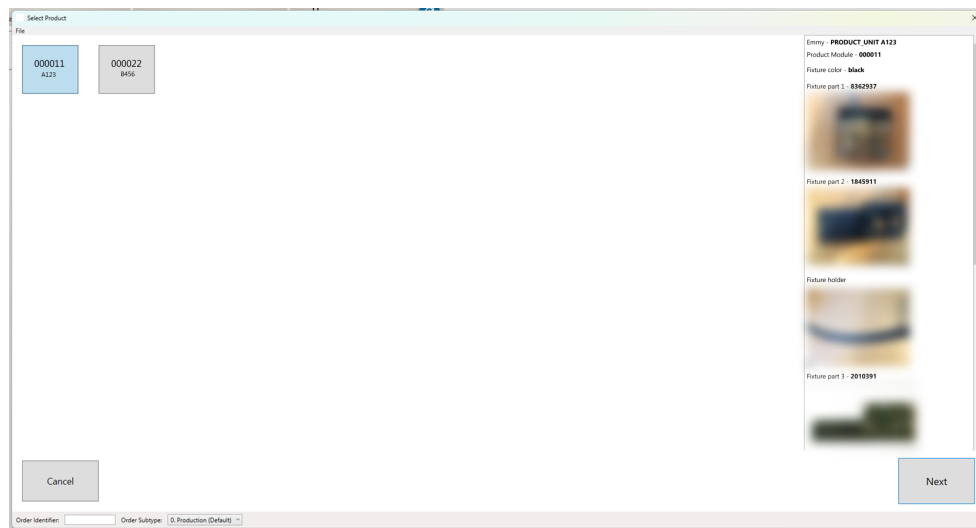


Figure 3.6 Product Information Field showing details for the selected product

The screen presented after the machine has been activated is shown in Figure 3.7 and enlarged in Figure A.4. At the top of the interface, three beige cards display key information. Two of these cards present general machine-related details, while the third tracks production statistics, including the number of produced units, where each unit represents an individual camera product, and how many have passed or failed. The blue icon within this card allows the operator to reset these counters.

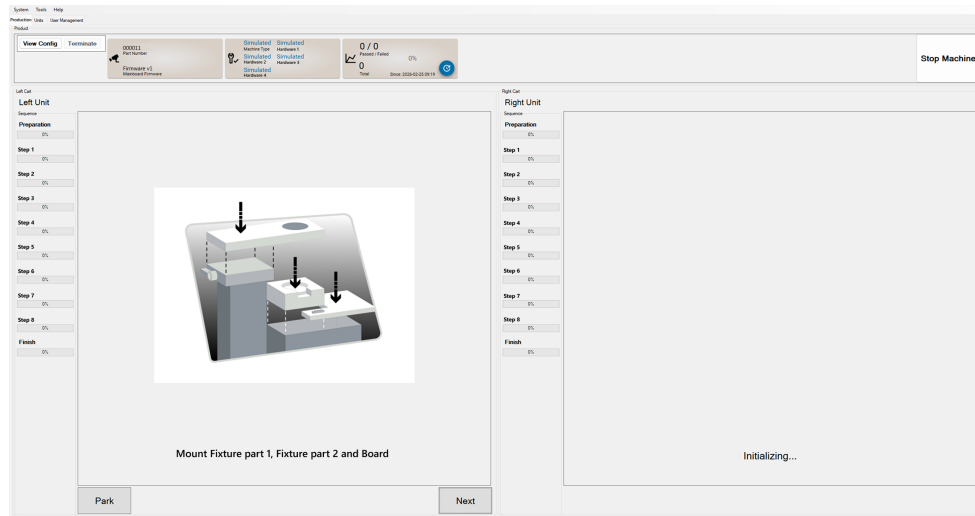


Figure 3.7 Mounting instructions displayed after machine activation

The main area of the interface is divided into two halves, reflecting the system’s capability to manage two products simultaneously. Although only one product can physically be inside the machine at any given time, the second product can be prepared in parallel while waiting for its turn. Focusing on the left cart, the left-hand panel lists all process steps along with their corresponding progress bars. In the central area, an instructional image is displayed illustrating how to mount the fixture components of the machine.

The workflow for a typical product unit can be described as follows. After the fixture components have been mounted, the first of three preparation steps is presented. Figure 3.8 shows the initial step, in which the operator must scan the product unit using the scanner depicted in the image. Once the unit has been scanned, two additional instructional images are displayed, illustrating how the product should be mounted. The final action before the preparation phase is complete, and before the unit is transferred into the machine, is to scan the “precal” label. This final scan is presented as a pop-up window in the center of the entire interface, as shown in Figure 3.9.



Figure 3.8 First preparation step with instruction to scan the product unit

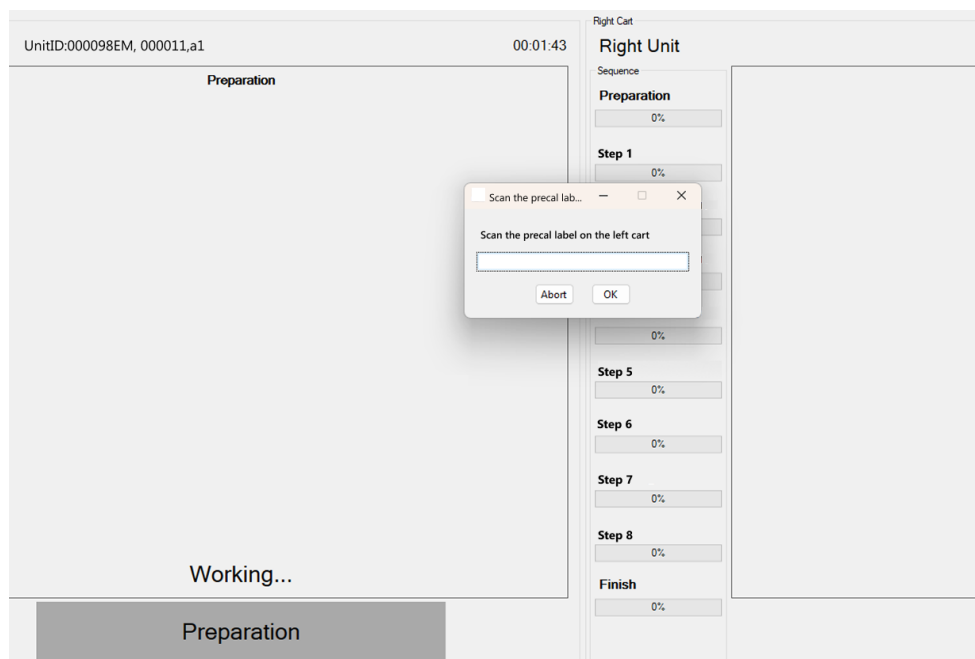


Figure 3.9 Pop-up window prompting the operator to scan the precal label

While the machine is running, the interface displays the ongoing process, as illustrated in Figure 3.10. Depending on the specific step being executed, this view may present a graph, an image, or in some cases no visual element at all. A light blue status field is also shown at the bottom of the screen, providing the operator with continuous updates on the current operation.

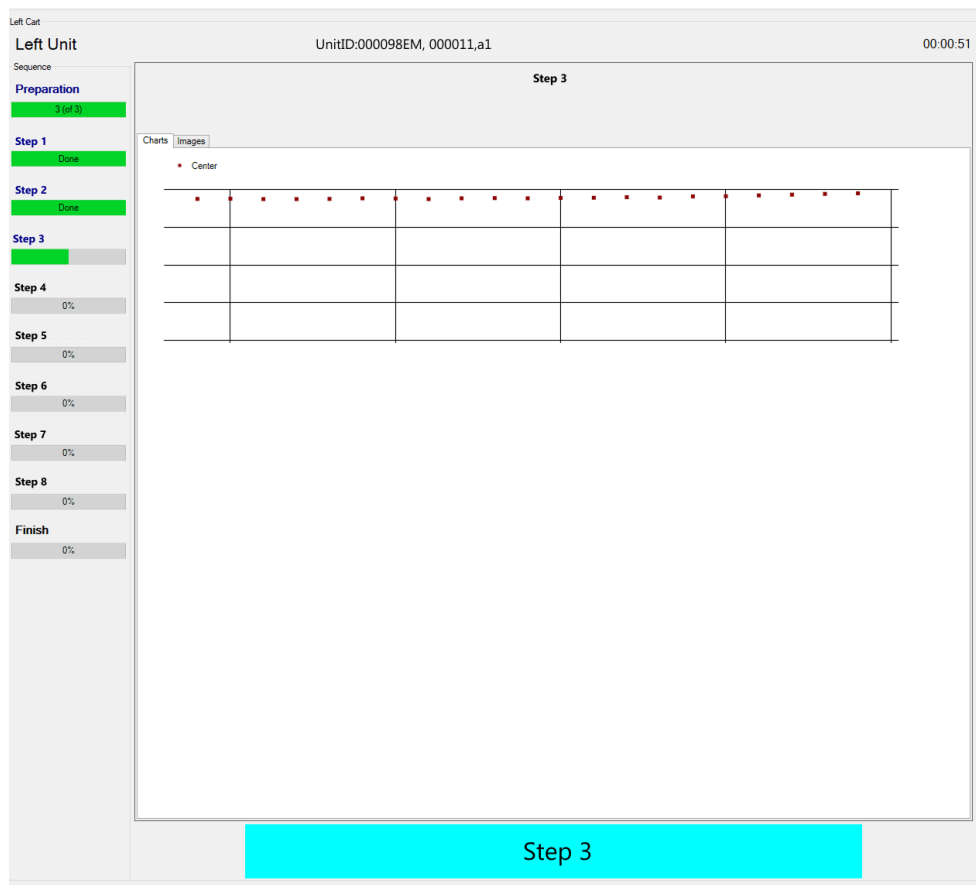


Figure 3.10 Process view displayed while the machine is running

After a successful completion of the process, the interface transitions to the view shown in Figure 3.11, where the status field displays “Finish”. In the main area, an instructional image is displayed, guiding the operator on how to remove the finished unit from the machine. Once this step has been completed, the operator can proceed to run the next unit.

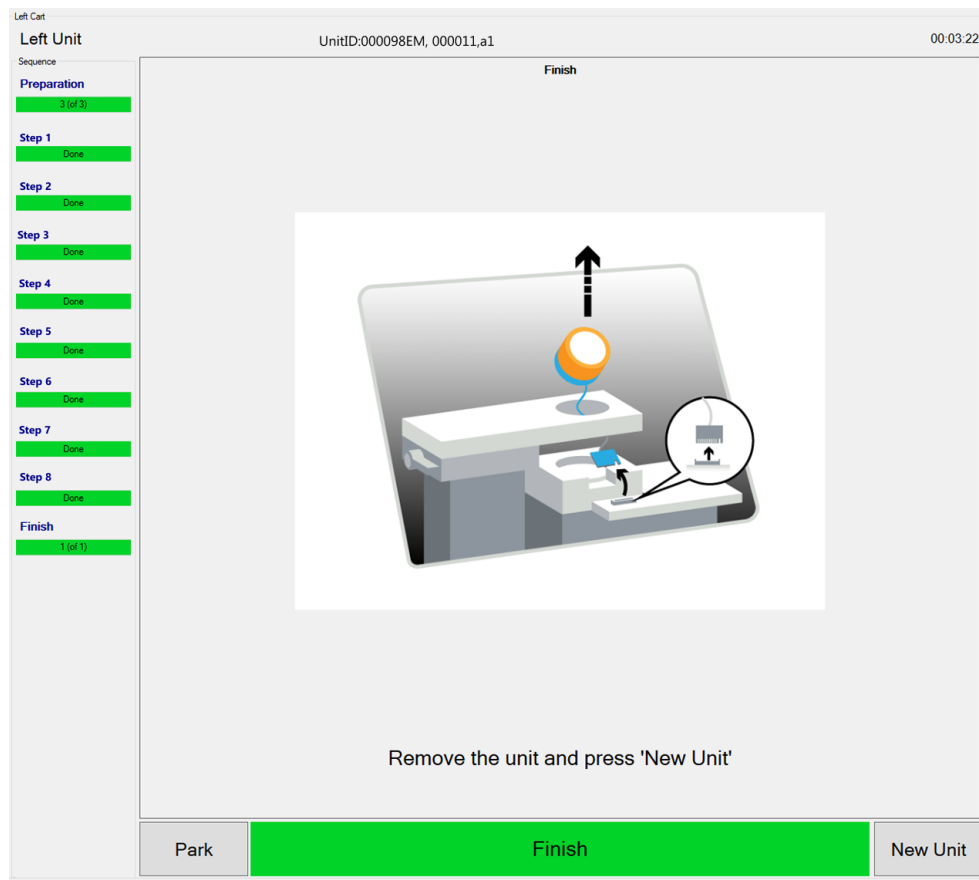


Figure 3.11 A successful process and instructions for removing the unit

If the process fails, the final screen appears as shown in Figure 3.12, where the status field displays “Finish” with a red background and an error message is shown in bright red text.

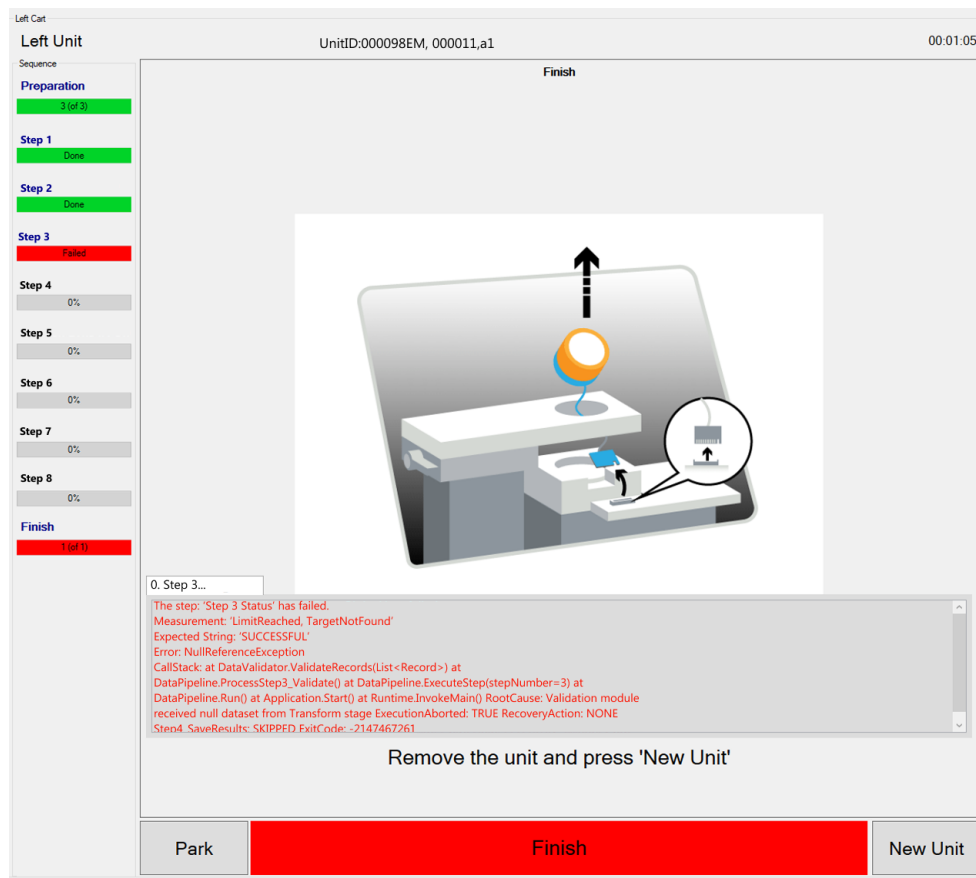


Figure 3.12 A failed process, showing error message and status

Above the progress bars, the step text turns blue once a step has been completed, indicating that it becomes a clickable link. This allows the operator to access the associated images or graphs at any time during the process. In the case of an error, selecting this link brings the user directly to the step at which the failure occurred, along with the corresponding error message, as shown in Figure 3.13. At this point, the system permits the operator to restart the process with a new unit.

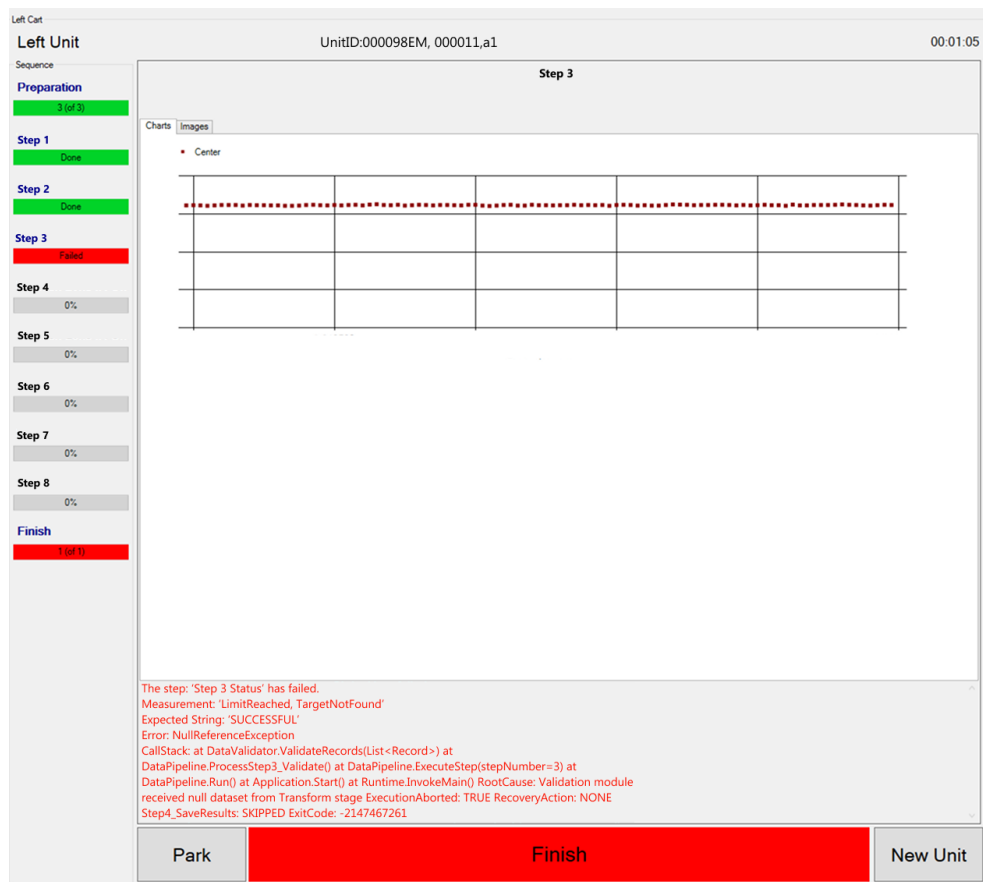


Figure 3.13 Failure details accessed via completed step

3.2 Heuristic Evaluation

In order to gain a deeper and more detailed understanding of the camera production system interface, a heuristic evaluation was conducted using Nielsen's usability heuristics [14] described in Section 2.2.2. As the evaluation was conducted by the authors of this thesis, no external participants were required. Additionally, the interface was examined in three parts: the product selection process, the main process of progressing through the production steps, and the error messages and how they are presented within the system. This division made it possible to identify usability issues as well as suggested solutions in a systematic and comparable manner across both methods.

3.2.1 Issues

The issues identified during the heuristic evaluation are summarized in Tables 3.1 and 3.2. Each issue is categorized by the heuristic it violates and the interface section where it was observed. These represent the usability issues that were considered most relevant to the scope of this project and were therefore included in the analysis.

The results show that several problems relate to visibility of system status, match between system and the real world, consistency and standards, recognition rather than recall, and aesthetic and minimalist design. In the product selection phase, issues often stem from unclear visual hierarchy and interactive elements that are not properly indicated. Within the main process steps, inconsistent progress feedback and ambiguous terminology pose challenges to operators. Finally, the error messages display a range of problems, including overly technical language, unclear corrective instructions, and visual issues like overlapping messages and rapidly disappearing fault images.

Table 3.1 Identified heuristic violations across interface sections - Part 1

Heuristic #	Product Selection	Process	Errors
1: Visibility of System Status	- Titles not large enough for pop-up - Progress bar shows inaccurate half-progress - Fixation step shows conflicting state info - “Precal” scanning step missing from sequence	- Detailed fault image shown too briefly - Finish appears as its own step with no action	- Aborting “precal” causes inconsistent “Finish” colours
2: Match Between the System and the Real World	- Meaning of various numbers unclear - Reset icon misleading - Terminology shortened, reducing clarity	- Ongoing status colour overly bright	- Technical terminology in error messages hard to understand
3: User Control and Freedom	- “Select Product” pop-up does not block background - Checkbox state does not reset when cancelling	- “Precal” placed after “Start”, prevents going back	
4: Consistency and Standards	- “File” button not visually identifiable - Inconsistent labels (“Abort”)	- Button design inconsistency - Preparation step incorrectly shows “Finish”	- Stop Machine pop-up uses wrong terminology (“sockets”)
5: Error Prevention	- Changing order subtype may cause malfunction	- Reset triggers without warning	

Table 3.2 Identified heuristic violations across interface sections - Part 2

Heuristic #	Product Selection	Process	Errors
6: Recognition Rather than Recall	- Instruction only appears when grid is empty - Missing project names - Product Information Field lacks description	- Product Information Field unavailable during workflow - Links not visibly clickable	
7: Flexibility and Efficiency of Use	- Requires two steps (“File” → “Configure Product Grid”)	- Too many instruction images for expert operators	- Same information for all users → unnecessary clutter
8: Aesthetic and Minimalist Design	- Order identifier rarely used - Order subtype adds clutter	- Percentage disappears from progress bars - Step titles duplicated - Progress bars contain unnecessary text	- Error message overlaps dismount image
9: Help Users Recognize, Diagnose, and Recover from Errors		- Incorrect “precal” shows technical unclear pop-up	- Faulty scan reveals scanned data - Error messages lack guidance
10: Help and Documentation	- Instruction text too small - Unclear instruction images		- No available documentation

3.2.2 Suggested Solutions

Overall, the heuristic evaluation revealed minor yet systematic usability issues that directly affect operator efficiency and accuracy. To address these findings, the identified suggestion improvements were organized into a set of overarching solution themes. These themes are summarized in Table 3.3.

Together, these solution themes address both surface-level inconsistencies and deeper structural challenges within the interface. Standardizing terminology and ensuring consistent button design increases predictability, while improving visibility, keeping key information accessible, and reducing visual clutter support faster interpretation of system states. Enhancing error messages and hiding unnecessary information help operators understand and recover from issues more effectively. Finally, simplifying the workflow and offering clearer documentation directly support operator efficiency. When combined with insights from usability testing, these themes provide a solid foundation for guiding the design of a new system that better supports operator needs and overall usability.

Table 3.3 Identified solution themes and example improvements

Theme	Example
Standardize terminology	Use plain-language error messages
Fix inconsistent button design	Make button styling consistent
Improve visibility and visual hierarchy	Show true progress in the progress bar
Keep important information visible	Make the Product Information Field accessible during the process
Clarify error messages and reduce technical language	Replace technical errors with clear, actionable operator messages
Hide sensitive or irrelevant data	Hide unnecessary detailed information for common operators
Reduce unnecessary steps and simplify the workflow	Incorporate all steps into the predefined steps
Provide better help and documentation	Offer concise descriptions of common errors

3.3 Testing Process

This section outlines the testing process, which employed a triangulated methodological approach consisting of usability testing, an interview, and a survey. By combining task-based scenario work with qualitative reflections and operator-level feedback, the process provided a comprehensive basis for analysing how the system is understood and used. The subsections that follow describe the participants, test environment, and procedural steps in detail.

3.3.1 Usability Testing

To evaluate the usability and user experience of the current system interface, usability testing was conducted. The purpose was to understand how users experience and interact with the system in order to gather requirements as a foundation for creating an improved interface concept for the next-generation system. Before conducting the main test sessions, a pilot test was carried out to ensure that the tasks, instructions and test setup functioned as intended. The process then consisted of interviews, task-based scenarios and a questionnaire, resulting in both qualitative and quantitative data.

3.3.1.1 Participants

A total of eight employees from the company participated in the usability testing. Since the primary end users, actual operators, were located across several countries outside Sweden, the test sessions were conducted with non-operator employees at the company who had varying degrees of familiarity with the system. The participant group represented a mix of professional roles, including product imaging engineers, site engineers, Quality Assurance testers, and employees working with software and machine programming. This diversity provided a broad range of perspectives for evaluating the interface. The participants' ages ranged from 27 to 48 years, with an average age of 34.9 years and a standard deviation of 6.8 years.

To capture differences in prior familiarity with similar systems, each participant was assigned an expertise level based on a brief background assessment that asked about their work tasks, responsibilities, and previous experience with comparable systems. The four-level scale reflected how frequently participants worked with related interfaces and how confident they felt using them.

Expertise Levels:

Level 1 – No prior experience:

The participant had not previously used comparable interfaces and approached the system as a novice.

Level 2 – Limited experience:

The participant had some exposure to similar systems but used them infrequently and did not feel confident in their operation.

Level 3 – Moderate experience:

The participant was regularly exposed to the underlying system and had a functional understanding of standard features and workflows.

Level 4 – High experience:

The participant frequently worked with the system and possessed substantial domain knowledge.

The participant pool covered the full expertise scale, ranging from level 1 to level 4, with an average expertise level of approximately 2.4. Three of the eight participants were classified at level 1, giving the sample a slight skew toward lower prior experience, while still offering perspectives from both novices and highly experienced users, as seen in Figure 3.14.

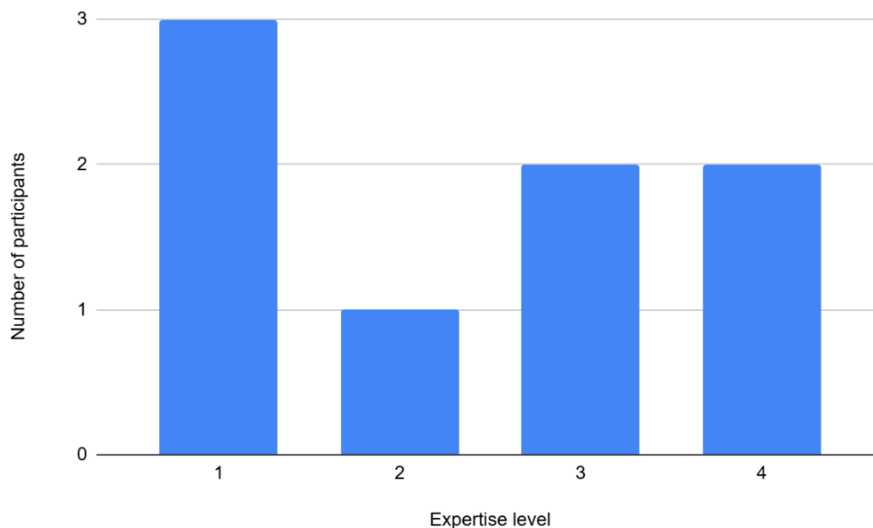


Figure 3.14 Pre-study: Participants by expertise level

3.3.1.2 Setup

The test session was conducted in a conference room at the company, where participants could remain undisturbed. Since the sessions focused on the system interface of the production machine rather than the physical machine itself, the system was therefore tested on a computer simulation. This made it possible to conduct the test session in a quiet room instead of a lab. Furthermore, it allowed the participants to focus solely on the system itself without getting distracted or confused by the physical machine.

Inside the room, participants were seated on a chair between the two facilitators, as illustrated in Figure 3.15. One facilitator introduced the scenarios and acted as a note-taker, while the other asked the pre- and post-test questions and managed the technical setup. In front of the participant was a touchscreen matching the size of those attached to the machine. Next to the touchscreen, a camera fixture with two QR codes attached and a scanner were placed. These objects served as props to create a more realistic operator setting. The camera fixture was not intended for interaction, apart from scanning the two QR codes placed on top of it. During the session, both the touchscreen interactions and the participants' voices were recorded using Microsoft Teams. Each usability test session lasted approximately 25–40 minutes.

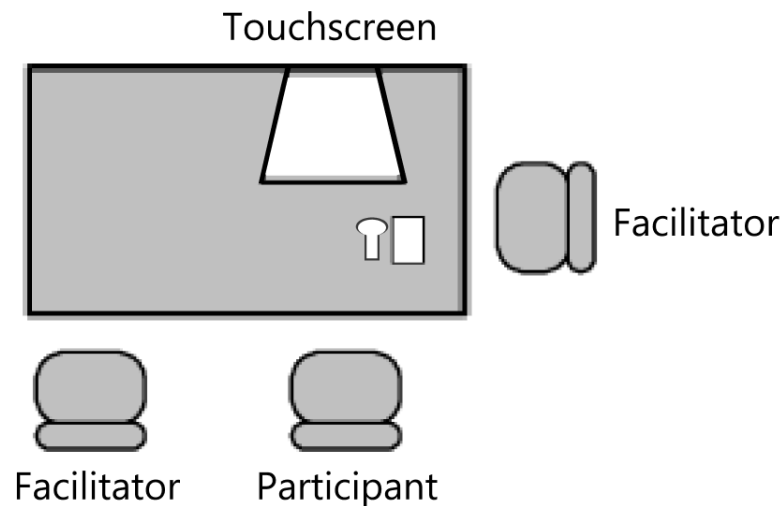


Figure 3.15 Pre-study seating setup

3.3.1.3 Procedure

Prior to the test session, each participant was sent an invitation containing a consent form via Outlook, which was asked to be read before arriving at the session. Each session was then conducted according to a structured procedure, as described in Figure 3.16. Upon arrival, participants were given an overview of the intended procedure, as well as an introduction to the purpose of the session and facilitator roles. Following this, participants were asked to give their consent in accordance with the consent form.

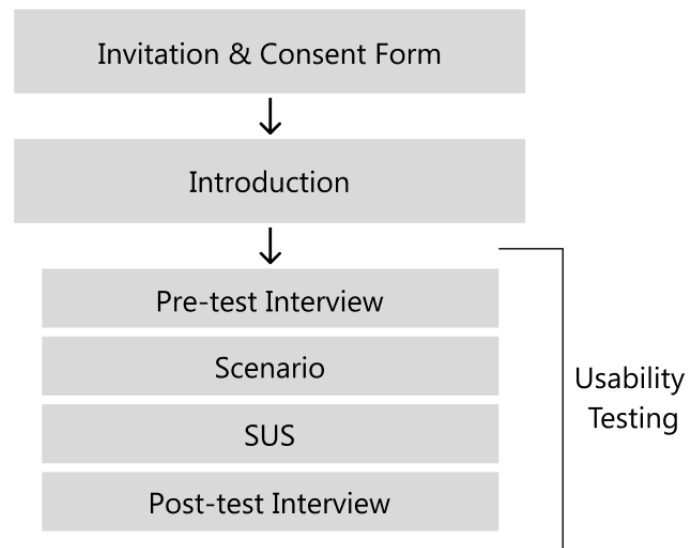


Figure 3.16 Procedure

After participants' consent had been obtained, the recording was initiated and the first phase of the usability testing began. This phase consisted of a pre-test interview, starting with a question asking whether the participant had any prior knowledge of the camera production machine. The response to this question determined the direction of the following questions asked. For the participants with prior experience, the following questions focused on when and how often they had been in contact with the machine, as well as how comfortable they felt using it. For participants without prior experience, the questions instead explored their familiarity with similar production machines and their general comfortability with learning new systems.

The second phase of the session consisted of usability testing with task-based scenarios. Participants were instructed to act as if they were using the system in real-life and to think aloud through the process, describing what they were doing, what they were expecting to happen, and if anything felt unclear.

Additionally, help was only provided if absolutely necessary in order to avoid influencing participants' behaviour and to better reflect natural interaction with the system. Task success was also considered as part of the usability evaluation. However, since all participants were able to complete the given tasks without failure, this measure did not provide meaningful distinction and was therefore not included in the analysis.

Scenario 1

The first scenario required participants to run an entire process from start to finish. They were instructed to start the machine, select a product, and complete the full assembly procedure. The purpose of this task was to evaluate the overall smoothness and coherence of the system workflow.

Scenario 2-4

In Scenario 2-4, participants were asked to run the process again. However, during each of these scenarios, a different was introduced by a facilitator. Participants were instructed to identify the issue and attempt to find suitable solutions. These tasks were conducted to observe how participants encountered failures and what information they searched for.

Scenario 5

Scenario 5 focused on stopping the machine and switching between different products. Participants were simply instructed to select a new product. This task was intended to assess whether participants understood how to stop the machine and navigate back to the product selection interface. Additionally, it examined whether participants remembered where product options were located, as the instruction shown during scenario 1 was no longer visible once a product had been placed in the grid.

Following the second phase of the usability testing, the third phase consisted of participants filling out a SUS questionnaire. The questionnaire was available for participants to interact with on the touchscreen, allowing them to complete it independently and at their own pace.

The last phase of the usability testing consisted of a semi-structured post-test interview, with the purpose of gathering qualitative reflections on the overall user experience, as well as suggestions for possible improvements. The questions addressed participants' overall experiences, including what they perceived as working best and what they found most challenging. Participants were also asked if they found any information displayed as excessive or insufficient. Additionally, more specific questions focused on their perceptions on the errors encountered in Scenario 2-4, as well as their opinions on the progress indicators displayed throughout the process.

3.3.2 Interview

To complement the usability testing, a separate interview was conducted to gain further insight into the system and its intended use. The interview was conducted with a site engineer, who has an understanding of the operators' work practices. While operators are responsible for operating the machine, site engineers have a deeper knowledge of the machine's mechanics and are typically consulted when technical issues occur. While conducting usability tests directly with operators was impossible, interviewing a site engineer remotely provided insights into the structure of the manufacturing site, as well as common situations where operators seek assistance.

Prior to the interview, the participant received a consent form. It was conducted remotely via Microsoft Teams and audio was recorded for analysis purposes. The semi-structured interview consisted of questions regarding both the operators as end users, as well as the interface of the machine. Questions included user demographic, frequency of machine use, language limitations, and machine training. Additional questions addressed interface interactions, information clarity, navigation flow, and commonly encountered errors. Broader reflective questions about overall impressions and suggestions were asked to conclude the interview.

3.3.3 Survey

In addition to the usability testing and interview, a survey was distributed to operators at a later stage. Direct contact with operators had initially been limited, however, due to contact with a site engineer at a manufacturing site, the opportunity to distribute the survey arose. As operators are the primary end users, collecting their opinions was highly beneficial, as it provided an additional source of information.

The survey consisted of four close-ended questions using a five-point Likert scale, ranging from "Strongly disagree" to "Strongly agree". The statements addressed different aspects of the operators' interaction with the system, including operator comfort when using the interface, understanding of the English interface, the usefulness of the information provided, and error message clarity.

Furthermore, six open-ended questions were included allowing participants to provide more elaborate answers. These questions focused on the error messages, including both the clarity and how operators usually handle error occurrences. Further questions addressed what operators found most useful, where problems and hesitations usually occur, and their overall experience with the interface. Additionally, participants were asked to provide any suggestions for improving the interface.

Due to the operators being located in Poland, and English not being their primary language, the survey was therefore translated into Polish. This way, operators got a full understanding of the questions and allowed them to answer the questions more confidently. Before sending the survey out, it was reviewed by a polish-speaking employee at the company.

3.4 Testing Results

This section presents the findings from the usability testing process. The results are derived from a combination of usability test sessions, interviews, and survey data, enabling both qualitative and quantitative analysis of the system's usability.

3.4.1 Affinity Diagram

To structure, analyse and make sense of the qualitative data gathered, an affinity diagram approach was used. This section therefore includes both the usability test data and the interview data. All recorded user sessions and the interview were transcribed and translated using the built-in features in Condens. The data was then analysed collectively in a single affinity diagram process before being clustered into themes.

3.4.1.1 Clustering Process

The clustering process began with extracting all relevant user quotes and coding them with tags indicating whether they represented positive feedback, negative feedback, or concrete improvement suggestions. It later became clear that the feedback naturally aligned with three broader areas of the system, namely Product Selection, Process and Errors. These areas corresponded to the same three parts analysed in the heuristic evaluation and offered a more meaningful way to organize the material.

The organization for the Process category is illustrated in Figure 3.17 and enlarged in Figure A.5, which displays the associated user quotes used in the clustering. Each quote was then placed into one of the three areas, enabling patterns to emerge both within and across the categories. By grouping related observations, recurring themes could be identified, highlighting common usability issues, elements of the system that functioned well, and potential opportunities for improvement, as shown in Figure 3.18 and enlarged in Figure A.6. This approach provided a coherent overview of participants' experiences and supported a more focused interpretation of the findings.



Figure 3.17 Quotes from Affinity Diagram

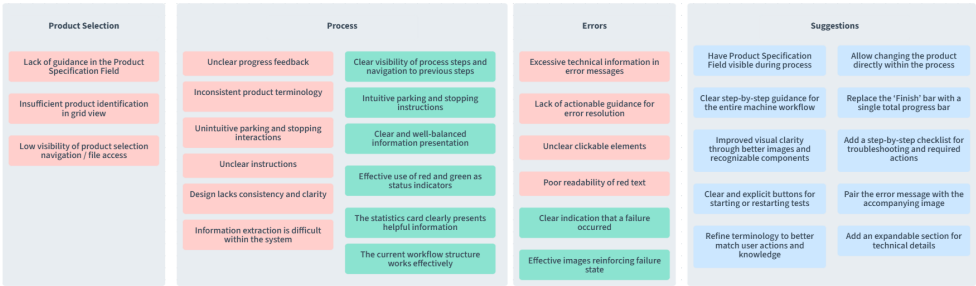


Figure 3.18 Pre-study: Affinity Diagram Themes

3.4.1.2 Results of the Affinity Diagram

The affinity diagram resulted in four main categories: Product Selection, Process, Errors, and Suggestions. These categories organize the clustered insights and highlight both strengths and challenges identified during the usability tests. This section describes the content of each category and the themes that emerged, as seen in Figure 3.18.

Product Selection

The Product Selection category captured user feedback related to how products are located, identified, and chosen within the system. Several issues emerged, including two out of the eight participants who struggled with insufficient product identification in the grid view, making it difficult to distinguish between similar items. A further three participants expressed uncertainty due to the limited guidance in the Product Information Field, noting that it was unclear what the different pieces of information referred to or why they were important. Additionally, five participants commented on the low visibility of the product-selection file-access options, which made it unclear where to access or adjust which products were available. Together, these issues suggest that users felt unsupported during the selection stage and had difficulty forming a clear understanding of the available product options.

Process

Feedback related to the Process category focused on how users navigated and understood the step-by-step workflow. Issues related to clarity and guidance were recurring. Two participants reported unclear progress feedback, leaving them uncertain about how much of the workflow remained, while five participants experienced unclear instructions more generally. At the same time, four participants noted that the visibility of process steps and the ability to navigate back to previous stages were clear, and another four described the information presentation as clear and well balanced.

A second area concerned terminology and information structure. Two participants noted that inconsistent product terminology caused confusion when different words were used for the same function or item and one participant found it difficult to extract relevant information from the interface. In contrast, the pass/fail information in the production statistics card was considered helpful and informative by one participant and five participants viewed the overall workflow structure as functioning effectively.

The final area related to interaction quality. Two participants described the parking and stopping interactions as intuitive, while another two found them unintuitive. Users also commented on inconsistent design elements, a point raised by two participants, whereas one participant noted that the use of red and green status indicators effectively communicated system states. Taken together, these patterns show that while the workflow supports users in some ways, inconsistencies in terminology, guidance, and interaction design still hinder a smooth and fully intuitive process.

Errors

A third area concerned how errors were presented and communicated to users. All eight participants noted that the error messages contained excessive technical information, making them difficult to interpret, and four participants mentioned that the messages lacked actionable guidance for resolving the issues. Additional concerns included unclear clickable elements, raised by one participant, and poor readability of red text, also noted by another participant. At the same time, some aspects of the error presentation were perceived as positive, including three participants who appreciated the clear indication that a failure had occurred, and another three found that the accompanying images effectively reinforced the failure state. The findings illustrate a balance of weaknesses and strengths in how the system currently communicates and presents errors.

Suggestions

Even though additional suggestions were mentioned by participants, only those considered relevant for the design of the new interface are included here. The selected suggestions reflect improvements that participants believed would better support the workflow in a redesigned version. Two participants recommended making the Product Information Field visible throughout the entire process, and another two emphasised the need for clearer step-by-step guidance across the machine workflow. Improved visual clarity was also highlighted by two participants, who suggested using better images and more recognisable components. In addition, three participants proposed adding a step-by-step checklist to support troubleshooting and required actions. Refining terminology to better match user actions and existing knowledge was suggested by two participants, and another two recommended including an expandable section for technical details to support those who need more in-depth information. Together, these suggestions represent the aspects deemed most valuable to carry forward when designing the next-generation system.

3.4.2 System Usability Scale

The SUS questionnaire provided a quantitative measure of how participants evaluated the usability of the prototype. The individual scores, average score, and the threshold for what is considered good usability are shown in Figure 3.19, with values ranging from about 30 to just over 85. The average SUS score across all eight

participants was approximately 59.1, placing the prototype slightly below the commonly cited threshold of 68. While two participants (P4 and P7) rated the prototype well above this benchmark, several others provided much lower scores, including a notably low score from P3 which resulted in a wide spread of responses. This variation indicates that although some users found the interface relatively easy to use, others encountered difficulties, pointing to usability issues that should be addressed in the next iteration of the design.

SUS Score Evaluation

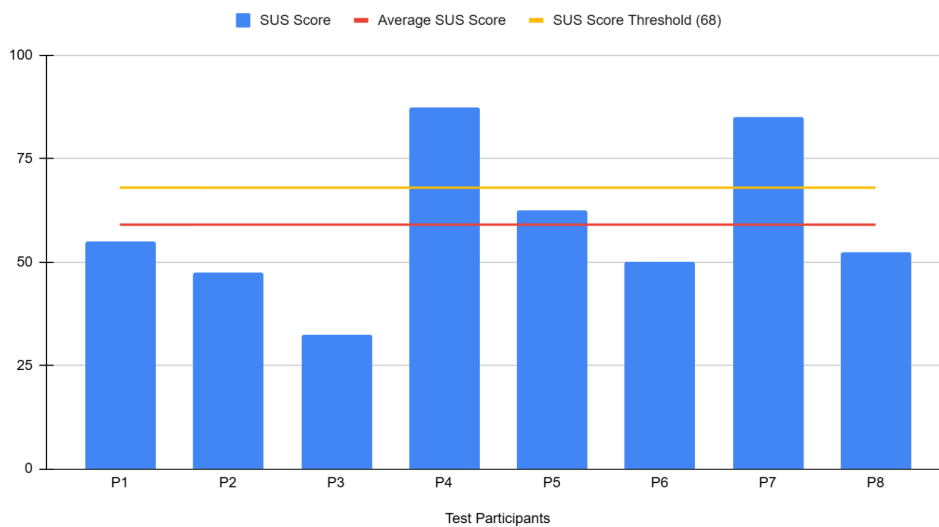


Figure 3.19 Pre-study: SUS scores with mean and threshold

There was an observable pattern suggesting that participants' level of expertise influenced how they evaluated the prototype. The first group of participants (P1-P4), who reported lower expertise levels with an average of 1.3, indicating slightly above no prior experience, produced an average SUS score of 55.6. In contrast, the more experienced participants (P5-P8), with an average expertise level of 3.5, representing a midpoint between moderate and high experience, rated the system slightly higher, with an average SUS score of 62.5. While the sample size is small, this pattern indicates a tentative relationship between expertise and perceived usability, where more experienced users may have found it easier to understand the workflow and navigate the interface. This may also help explain part of the variation in SUS scores across the participant group.

When examining the individual SUS statements, the items with the largest deviation from the ideal were Statement 2: "I found the system unnecessarily complex"

and Statement 10: “I needed to learn a lot of things before I could get going with this system”. Both statements received relatively high scores for negatively worded items being 3.1 and 3 respectively, indicating that several participants experienced the system as somewhat complex and requiring a certain amount of learning before they felt comfortable using it.

These findings align with the qualitative feedback, where participants expressed a need for clearer guidance, more structured instructions, and improved terminology to better support their understanding of the workflow.

3.4.3 Survey

The survey received a total of 11 responses, all from operators at a manufacturing site in Poland. As the responses were written in Polish, they were therefore translated into English prior to the analysis. The first close-ended question, based on the statement “I feel comfortable using the system interface”, produced the results shown in Figure 3.20. The majority of respondents agreed or strongly agreed with the statement, while two respondents disagreed and three respondents were unsure.

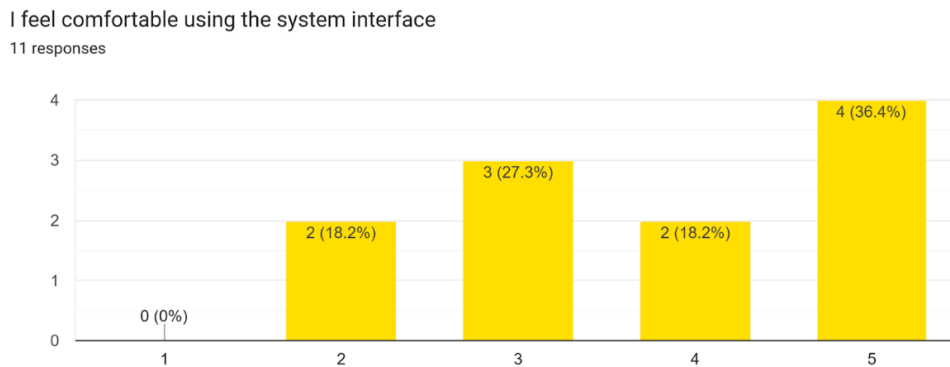


Figure 3.20 Survey statement 1

For the open-ended question “What is your overall experience of the system interface?” seven respondents said the interface was good, while two respondents stated that it was not good and one respondent did not know. Additionally, one respondent stated that “For beginner operators, the interface is unintuitive and not ergonomic.”

The question “What part of the interface do you find the most useful?” resulted in a variety of responses. One respondent mentioned the graphical elements, one mentioned the order in which the images are displayed, and another highlighted the pass/fail information shown. Two respondents stated that the test sequence was

useful, talking about the overview of the different steps the unit goes through. In contrast, another two respondents reported that they did not find any aspect of the interface useful.

For the question “What part of the interface causes the most problems and hesitation?” two respondents answered “Everything”, while three respondents answered “Nothing”. One respondent mentioned the lack of clear information after an error occurs, and two respondents stated that the interface not being available in Polish causes hesitation.

The statement “The English interface is easy for me to understand” addresses the language difference. The results shown in Figure 3.21 indicates that the majority of respondents did not experience difficulties with the English interface. However, four respondents were either unsure or disagreed with the statement.

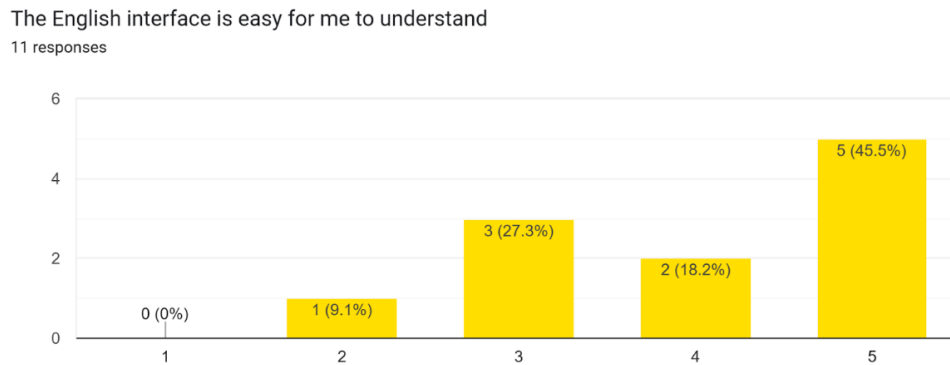


Figure 3.21 Survey statement 3

A set of questions focused on error messages. The statement “Error messages are clear and help me understand what to do” produced mixed responses, as shown in Figure 3.22. For the follow-up question “In what ways are the error messages helpful or not helpful for you?” five respondents found the error messages not helpful. One of the five respondents stated that the messages were difficult to understand because they were written in English. Three of the five respondents indicated that the messages were unclear and did not specify the cause of the error. One of these responses elaborated with “Error messages contain detailed technical data that may be incomprehensible or not useful for the operator. The message should be clear and include the specific name of the actual error so that the operator can provide clear and understandable information to a supervisor or technician.”. In contrast, four respondents stated that they experienced no issues and found the error messages understandable.

Error messages are clear and help me understand what to do

11 responses

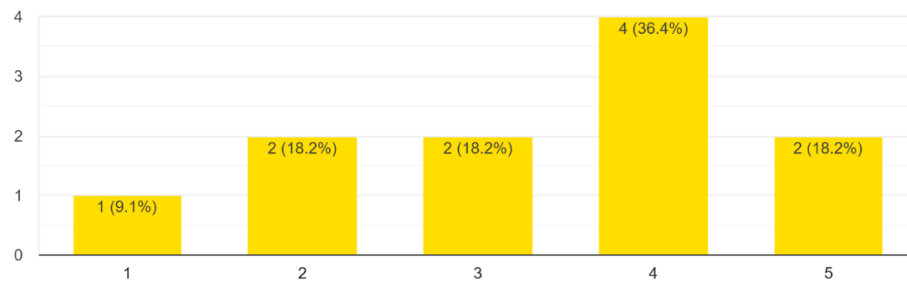


Figure 3.22 Survey statement 4

The final question, “Do you have any suggestions that could make the system interface easier to use?” also produced a range of responses. Two respondents suggested improving the error messages to present more clear causes of the errors and how to resolve them. Three respondents suggested adding a polish option, one respondent said that the visual design should be refreshed, while another suggested that all scanning should occur at the same time before the machine moves, as the machine currently moves between scans.

3.5 International Organization for Standardization Standard

The relevant ISO (International Organization for Standardization) standard defines seven usability principles, each accompanied by a set of recommendations. To ground the pre-study in established usability guidance, the principles are briefly summarized below.

1. **Suitability for the user’s tasks:** The system should match the user’s tasks and avoid imposing unnecessary, technology-driven steps.
2. **Self-descriptiveness:** The system should make its purpose, actions, and status immediately clear without external help.
3. **Conformity with user expectations:** The system should behave predictably by following established conventions and maintaining consistency.

4. **Learnability:** The system should be easy to discover, explore, and remember, minimizing required learning effort.
5. **Controllability:** Users should be able to control the pace, sequence, and form of interaction, including interruption and undo.
6. **Use error robustness:** The system should help prevent errors, tolerate user mistakes, and support efficient recovery.
7. **User engagement:** The system should motivate and engage users appropriately without compromising effectiveness.

During the pre-study, the identified principles were analysed to understand how they could support the development of the low-fidelity prototype. In these early exploratory stages, applying the full ISO standard would have overly constrained creativity and shifted the focus toward strategic compliance rather than broad ideation. Instead, a more focused approach was adopted by narrowing down the set of guiding principles. This allowed the process to maintain design flexibility while still grounding decisions in essential usability considerations.

Based on this reasoning, three principles were chosen to prioritize: Self-descriptiveness (2), Conformity with user expectations (3), and Use error robustness (6), as these were most directly aligned with the usability issues identified in the existing interface. Self-descriptiveness was selected because many of the system's current problems relate to unclear navigation, insufficient feedback, and ambiguous interface elements, making it essential to ensure that users can immediately understand available actions and system status. Conformity with user expectations was included due to the system's inconsistent terminology, layout, and interaction patterns, which currently disrupt predictability and increase cognitive load for operators. Finally, Use error robustness was prioritized because the analysis revealed several confusing, overly technical, or insufficiently supportive error messages, as well as error states that did not guide operators effectively toward resolution. Focusing on these three principles allows all prototypes, especially the early ones, to address the most critical issues in operator experience without restricting the creative exploration needed at this stage of the design process.

3.6 Personas

After the usability testing, interview, and survey, personas were created based on the test results in order to get a better understanding of the different end users and their respective goals. Creating personas made it easier to comprehend the different functions and views the system interface has to incorporate depending on which user

is operating the machine. Operators, site engineers, and developers, are the three types of end users for this specific camera production machine.

The first persona created, as seen in Figure 3.23, is 35 year old Wiktor, who works as an operator at a manufacturing site facility in Poland. He has worked there for 6 years and is responsible for operating the camera production machine. He works in a cleanroom environment maintaining the camera assembly and testing, making sure that cameras pass all the required tests. His work tasks include starting and monitoring the machine, loading and unloading camera modules, and reporting issues and errors to the site engineer. Since Wiktor uses the machine on a daily basis, he has developed a high level of familiarity with the machine and its system interface. Wiktor however is not so familiar with the technical aspects and finds challenges in understanding the error messages when they occur. Additionally, he only has a basic English comprehension and sometimes struggles with understanding interface terminology.



Figure 3.23 Wiktor, generated using AI assistance

The second persona, as seen in Figure 3.24, is Jakub. He is 49 years old and has worked as a site engineer at a manufacturing site in Poland for 15 years. As a site engineer, Jakub focuses on overseeing maintenance and monitoring on the machines, as well as writing documentation and communicating with partner companies. Jakub occasionally troubleshoots machine errors, as he has a very good understanding of technical aspects regarding the machine. However, he sometimes finds troubleshooting to be a very time-consuming process, as the error messages can be quite unstructured and difficult to interpret. Every so often, Jakub has to get additional help by sending a picture of the error message to the company that develops the machines.



Figure 3.24 Jakub, generated using AI assistance

The third persona, as seen in Figure 3.25, is 29 year old Alice, who has worked at the company that develops the camera production machines for 6 years working as a product developer engineer. Her main responsibility is developing camera products, which requires her to use the camera production machine as a testing tool. Her work tasks include configuring products to be compatible with the machine, using the machine to test and validate new camera designs, and analysing the results to improve product performance. Alice primarily uses the machine in a development

environment rather than a real production environment, giving her limited insight into operator experience during production. While Alice is confident with the machine, she may not know all technical aspects of it.

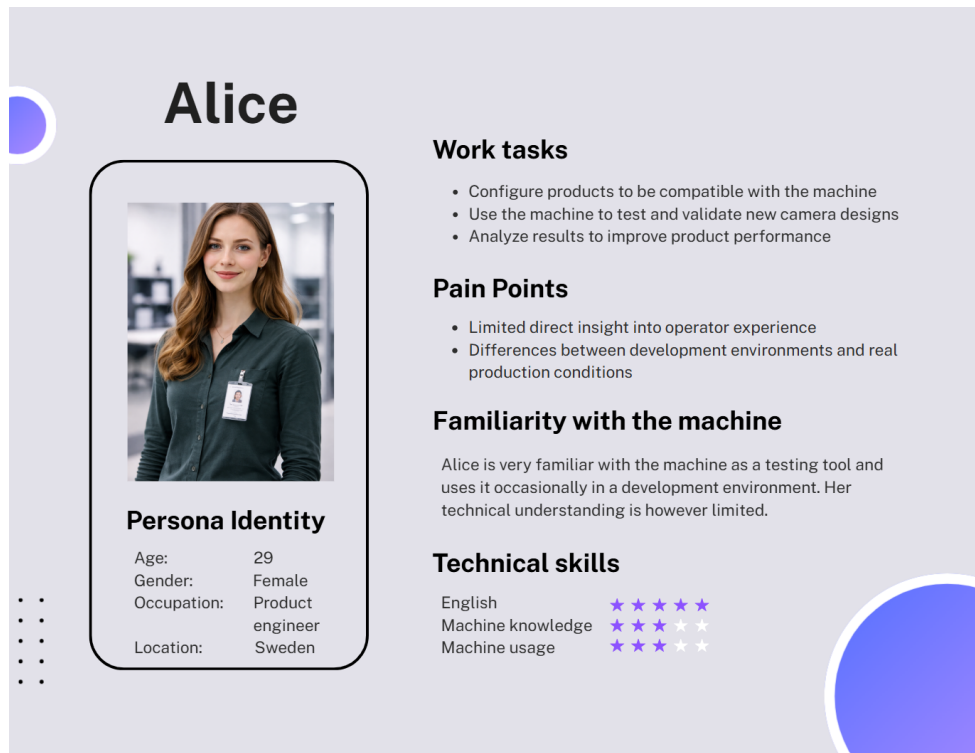


Figure 3.25 Alice, generated using AI assistance

3.7 Key Takeaways

Several findings from the current interface were found in order to provide insights into guiding the creation of the new interface concept. These findings address user needs, painpoints, and design principles that should be carried forward into the Lo-Fi prototype iteration.

Three main end users were identified: operators, site engineers, and developers. The primary end user for the design is the operator, as they interact with the system more frequently. Therefore, the design of the interface should be made clear, simple, and provide sufficient guidance. The needs of site engineers and developers should however not go unnoticed and features that could benefit them should be considered without negatively impacting the operator's experience.

The key issues identified in the product selection process included unclear terminology and difficulty finding the "File" button, where the product list is located. This created uncertainty and confusion among users. The main takeaway is to make the interface more coherent by improving terminology and visibility, ensuring that users feel confident selecting products.

Regarding error handling, nearly all participants and most respondents found the messages to be overly technical, lacking clear explanations of the cause, as well as how to resolve the issue. The system should therefore include more clear, informative, and user-friendly error messages, along with actionable suggestions for resolving the issue in a structured way.

Despite some specific workflow details being perceived as problematic, the overall step-by-step workflow was considered effective. This indicates that the existing structural representation should be maintained in the next design iteration. However, some inconsistencies in interface elements and terminology were identified, which can break user expectations. These issues can be resolved through consistency in design patterns and standardization in terminology.

The SUS results suggest that the system is somewhat complex and requires a certain amount of learning before it can be used effectively. The main takeaway is therefore to reduce cognitive load by simplifying interactions and improving guidance through more structured instructions.

Language limitations were widely mentioned by respondents, referring to difficulties related to the English interface. Optimally, the interface should minimize reliance on languages by incorporating clear visuals and intuitive design principles. However, providing language options would also be beneficial to improve usability, which in that case becomes an implementation issue.

Lastly, the selected usability principles from the ISO standard, Self-descriptiveness (2), Conformity with user expectations (3), and Use error robustness (6), align closely with the issues identified. These principles should therefore serve as important guidelines for the design of the Lo-Fi prototypes.

4 Low-Fidelity Design

This chapter describes the low-fidelity design process used to develop and evaluate early interface concepts for the new camera production machine interface. It covers ideation activities, the creation of alternative Lo-Fi prototypes, usability testing and results as well as a subsequent Lo-Fi iteration addressing updated machine requirements. The chapter concludes with key takeaways that inform the development of the high-fidelity prototype.

4.1 Ideation

The ideation phase began with individual brainstorming sessions conducted by the authors of this thesis, in which the views and interface elements required by the system were initially mapped out. Working independently made it possible to generate a broad range of early concepts without constraints, focusing on producing alternative layouts and interaction flows. These ideas were then consolidated in four collaborative brainstorming sessions, each lasting approximately two hours, where they were discussed, refined, expanded, and occasionally discarded, leading to new insights and clearer design directions. Each session focused on a certain area of the system, such as product selection, the process and errors. The resulting material was documented in a shared design file in which each sketch was accompanied by explanatory text and an example can be seen in Figure 4.1. The ideation process was also informed by the personas developed during the pre-study, ensuring that early concepts considered differences in user roles, levels of technical expertise and interaction needs. This helped guide decisions toward solutions that balance clarity for less experienced users with efficiency for more advanced operators.

Combine start and product selection
Start machine in top right corner - outgrayed before selecting product
Configurations in top left corner
Product selection in empty space underneath

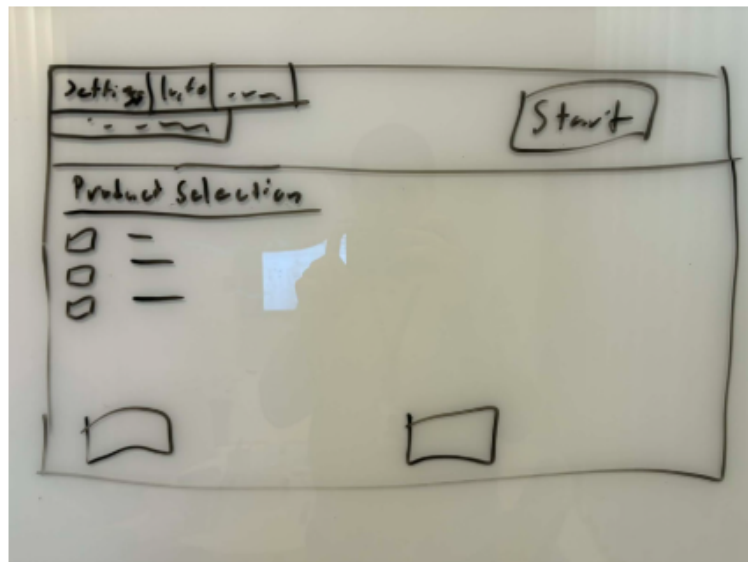


Figure 4.1 Product selection example with accompanying text

4.1.1 Key Design Considerations

Since both the heuristic evaluation and the usability tests indicated that the overall structure of the existing camera production interface was not a major issue, a complete redesign was not deemed necessary. Instead, the focus shifted toward areas that were perceived as less coherent, as well as concepts that needed to be introduced for the future machine, which the new interface is ultimately intended to support. The main design considerations that emerged from the combined analysis of the heuristic evaluation and user testing results were:

- Product selection: Streamlining the interaction and improving clarity
- Five-station machine setup: Introducing a progress overview and removing the existing “one frame per unit slot”-structure
- Load and Unload steps: Making the separation of actions clearer to reflect their distinct purposes
- Error handling: Defining a clearer and more structured way to present failures and errors

4.1.1.1 Product Selection

Even though selecting a product to run in the machine was generally perceived as straightforward, four participants struggled to locate where the available product list could be edited. The main reason for this was that they were unable to find the small "File"-button positioned in the top-left corner of the pop-up window, as shown in Figure 3.3. To address this issue, the easily overlooked "File"-button was replaced with a more prominent and intuitive "Add"-button using a distinct plus symbol to signal its purpose, as illustrated in Figure 4.2.



Figure 4.2 Product selection showing revised add button

4.1.1.2 Five-station Machine Setup

Since the existing machine only has two unit slots where units are handled by the operator and the machine, it is relatively easy for the user to understand what is happening at any moment. However, the new machine will include five unit slots,

which introduces significantly more parallel activity. Displaying all this information directly on the screen would not only overwhelm the user but also require substantial interface space. Therefore, a more efficient and compact way of presenting this information was needed. The proposed solution was to introduce a progress overview component that visually summarises the status of all units, as seen in Figure 4.3. This component shows both the current step each unit is on and which steps have already been completed. The frame is positioned next to the standard operator instructions, allowing users to quickly glance at it when necessary without it interfering with their primary tasks.

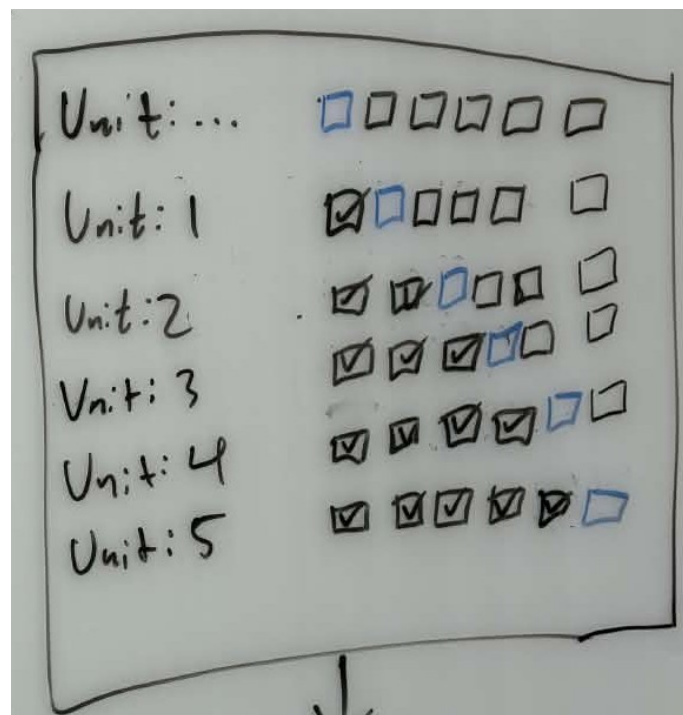


Figure 4.3 Early design concept for the progress overview

4.1.1.3 Load and Unload Steps

Another aspect of the new machine that significantly affects the operator's workflow is the increased frequency and importance of loading and unloading units. Since more units are processed simultaneously, these actions become more central to the operator's interaction with the system compared to the current machine. To make this workflow understandable and easy to follow, the progress overview was displayed together with the instruction image, which visually highlights whether the operator should load or unload a specific unit. The design approach involved separating the load and unload actions both from each other and from the automated

machine-handled steps. This distinction helped clarify which steps require operator interaction and which are performed solely by the machine. Two examples of how this can be visually represented are shown in Figure 4.4.

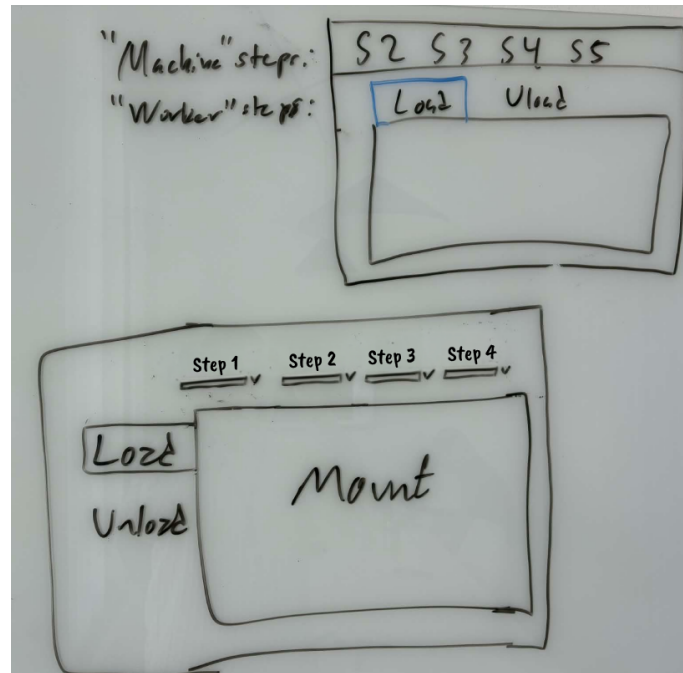


Figure 4.4 Brainstorming concepts for load and unload steps

4.1.1.4 Error Handling

An additional area of concern in the current machine's interface is the way failures and errors are presented to the operator. The existing design provides insufficient helpful information while simultaneously displaying excessive and overly technical details when a failure occurs, as shown in Figure 3.12. To address this, the goal was to create a clearer, more structured, and operator-oriented method for presenting failure information. In doing so, three elements were identified as particularly important: the interface must communicate the underlying cause of the failure or error, indicate which step in the process was affected, and specify whether any corrective action is available to the operator. A conceptual example illustrating this intended structure, though not containing finalized wording, can be seen in the middle frame of Figure 4.5.

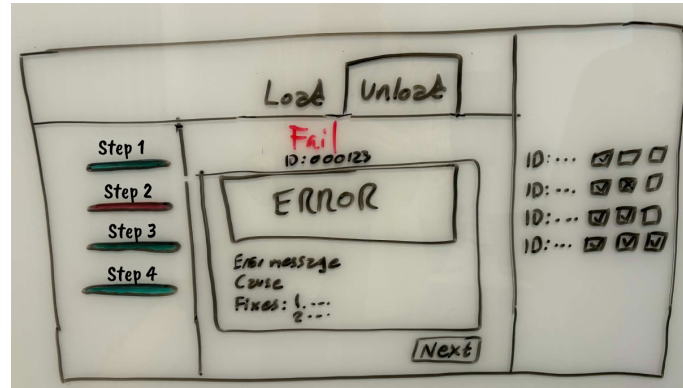


Figure 4.5 Early design structure for presenting error and failure information to the operator

4.2 Initial Lo-Fi Prototyping

After the ideation phase, in which initial design decisions and layout structures were established, the next step involved producing the Lo-Fi prototypes. The prototypes were developed using FigJam, a freeform whiteboard space available within the Figma application. FigJam enabled rapid prototyping by using basic shapes and minimal details in order to visualize ideas.

To explore different design solutions for each view, two separate prototypes were created: Version A and Version B. Both versions shared the same core functionality but differed in terms of layout, graphical elements, and component placement. This approach made it possible to compare the design alternatives, while identifying the most effective elements from each version. The intention was to develop a final version by combining components from both, rather than choosing one over the other.

4.2.1 Prototypes

The following sections present the initial Lo-Fi prototypes developed for the main system views. For each view, two alternative design versions, A and B, are shown and compared.

4.2.1.1 Product Selection

The first view represents the product selection. Version A is shown in Figure 4.6, while Version B is shown in Figure 4.7. The different versions represent two alternative design approaches. Version A resembles the current interface of the camera production system, as no major complaints were made regarding the existing layout

and design. Each product in the product grid is therefore presented as boxes, where selecting a product causes the information field to appear on the right. In contrast, Version B explores a new approach, where products are displayed in rows and the product information field is integrated within the corresponding row.

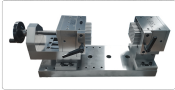
Production	Unit	User Management
Product Selection Emmy 00011 - A123 Morgan 00022 - B456 + Confirm		
Product Specification Emmy Module: 000011 Fixture color: black Fixture 1 - 2428472345  Connector 1 - 5252544  STOP Part Number: 00011 Machine data Mainboard Firmware: Firmware v1 Machine type: Simulated Hardware 1: Simulated Hardware 2: Simulated Hardware 3: Simulated Hardware 4: Simulated Yield Passed/Failed: 9/1 Total: 10 Since 26-03-16 10:00 Throughput last hour: 200 Average throughput: 300/h		

Figure 4.6 Product selection - Version A: Grid-based product layout

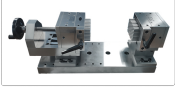
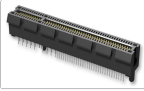
Production	Unit	User Management
Part Number: 00011	Machine configuration	Yield Passed/Failed: 9/1 Total: 10 Since 26-03-16 10:00 Reset Throughput last hour: 200 Average throughput: 300/h
Product Selection Emmy - 00011 - A123		
Product Specification Module: 000011 Fixture color: black Fixture 1 - 2428472345  Connector 1 - 5252544  Close Confirm		
Morgan - 000022 - B456		
+		

Figure 4.7 Product selection - Version B: Row-based product layout

One of the most frequently reported difficulties in the current interface was identifying how to configure the product grid. This issue was therefore addressed by introducing a more conventional and visible button to represent this action. In both versions, the button is placed after all products in the grid.

Additionally, in the current interface, selecting a product requires pressing a button labeled “Start”. This terminology may be misleading, as the machine does not actually start, but rather confirms the selection and proceeds to the next view. Therefore, the label was changed to “Confirm” in both versions.

The last key difference between both versions is regarding the layout and placement of the field containing additional information such as machine data and yield. These placements remain consistent throughout all views. In Version A, this field is placed to the far right of the screen, whereas in Version B it is placed at the top, where some of the information is also hidden under a button labeled “Machine configuration”.

4.2.1.2 Process

The two versions for the general process interface are presented in Figure 4.8 and Figure 4.9. The interface is divided into two main fields: the main screen and the progress overview.

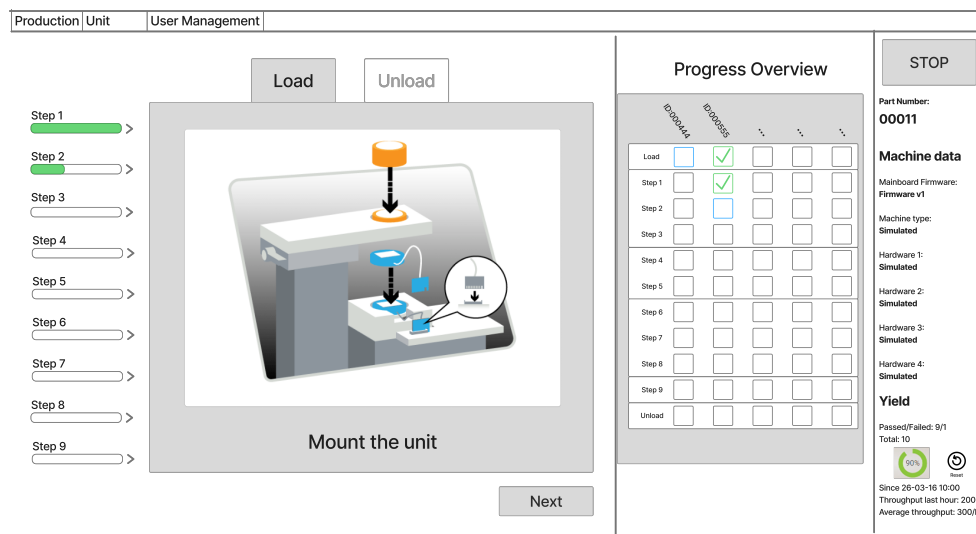


Figure 4.8 Process - Version A: Step-based layout and vertical progress overview

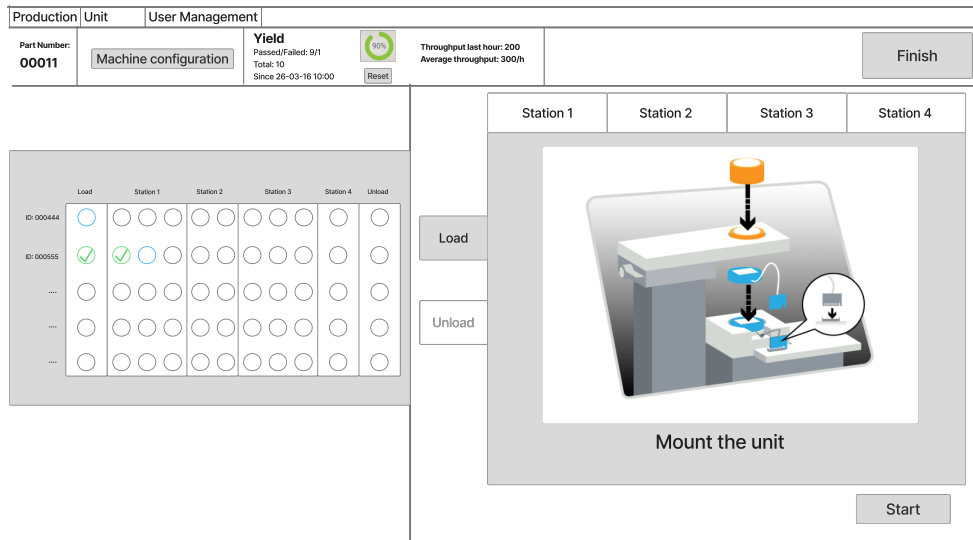


Figure 4.9 Process - Version B: Station-based layout and horizontal progress overview

There are three key differences between the main screens of the two versions. In Version A, the main screen is positioned on the left side, with “Load” and “Unload” located at the top, and the individual steps listed vertically along the right. In contrast, Version B places the main screen on the right side, with “Load” and “Unload” to the left of it, and the different stations listed horizontally. A key distinction between the two versions is that while Version A lists every step of the process, Version B instead lists the four stations. This approach was chosen to maintain a more compact and less overwhelming interface, as the number of steps might vary for each product, as well as increase over time, whereas the number of stations will remain constant. The individual steps are however still accessible in Version B by selecting a station. Additionally, another distinction is the use of progress bars, which are only available in Version A, and not in Version B.

The second main field, the progress overview, also differs between the two versions. In Version A, the overview is presented vertically, with steps progressing from top to bottom. The overview in Version B is instead horizontal, progressing from left to right. While a horizontal layout may be more intuitive for users to read, the vertical layout allows for greater scalability, as it provides more space to add new steps if needed. Furthermore, a minor design detail that differentiates the two versions is using squares in Version A and circles in Version B.

4.2.1.3 Step Status

One function added to the progress overview is the ability to select any square or circle representing a unit in order to see its specific step status. The status is then displayed in the main screen. Pressing a green button with a checkmark indicates that the step for that unit has been completed successfully, as seen in Figure 4.10 for Version A and Figure 4.11 for Version B. In contrast, pressing a red button with a cross mark indicates that the step has failed, while pressing a blue button indicates that the step is still in progress and ongoing.

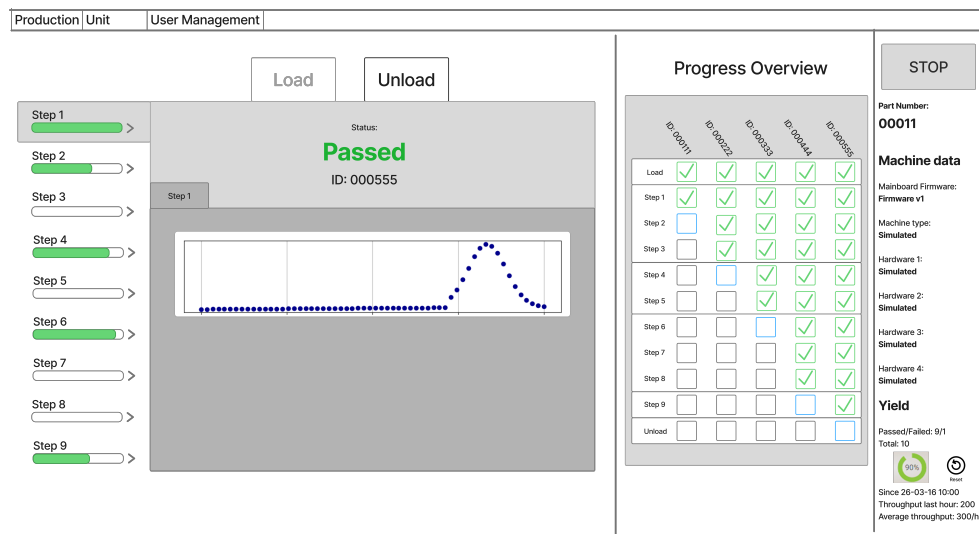


Figure 4.10 Step status - Version A: Completed step for a selected unit

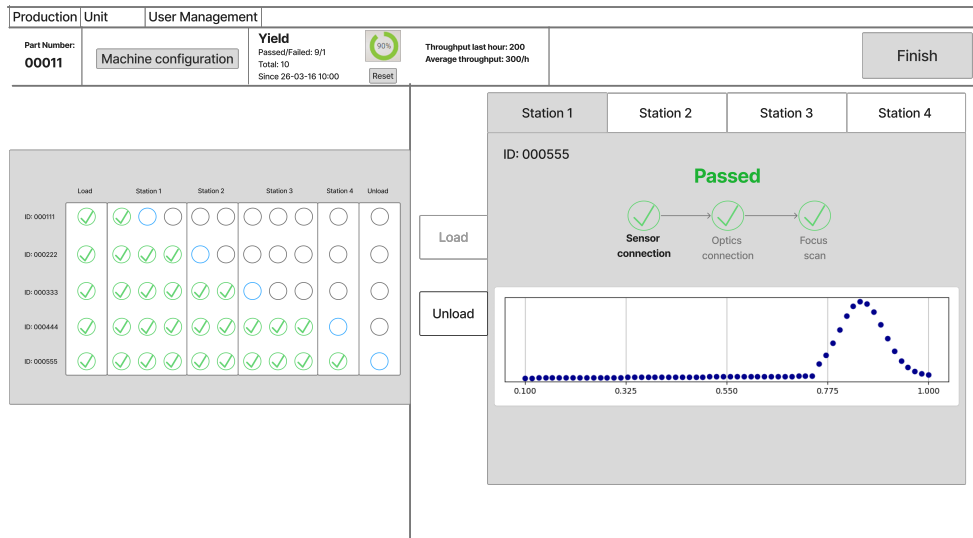


Figure 4.11 Step status - Version B: Completed step with station-based step details

The differences between the two versions are relatively minor. Since Version B only displays stations on top of the main screen, each step status contains the individual steps being performed within that station. These steps are, similar to the progress overview, displayed as circles that change colour depending on their status.

4.2.1.4 Fails

When a failed unit has completed the process and is ready to be unloaded, failure information is presented before the unloading instructions, as seen in both Figure 4.12 and Figure 4.13. The failure message differs significantly from the current interface which contained an overwhelming amount of information. Based on user feedback from the pre-study usability testing, the redesigned failure message presents information tailored to the operator, focusing only on relevant details such as the cause of the failure and potential resolutions. The biggest change from the current interface is the removal of the call stack, which was considered to be difficult to interpret. The new message is identical in both Version A and Version B.

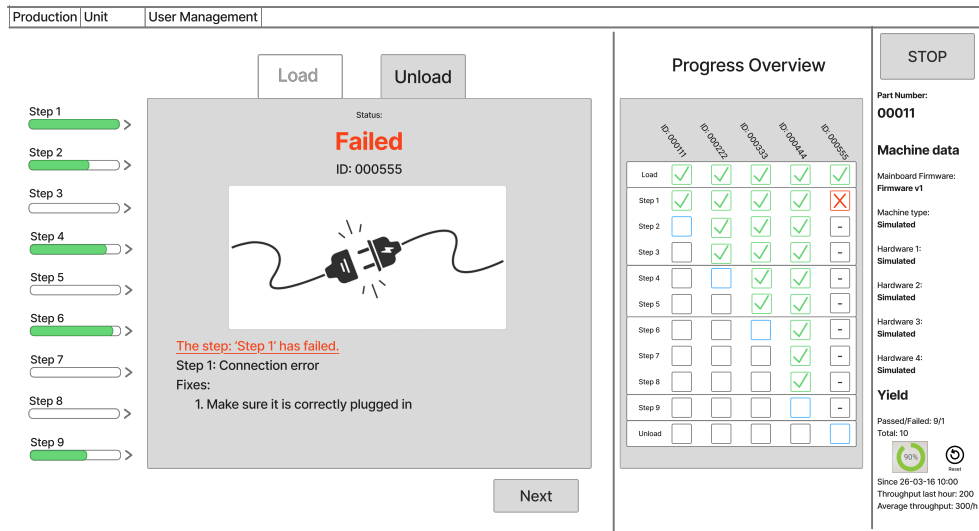


Figure 4.12 Failed step - Version A: Operator-oriented failure message

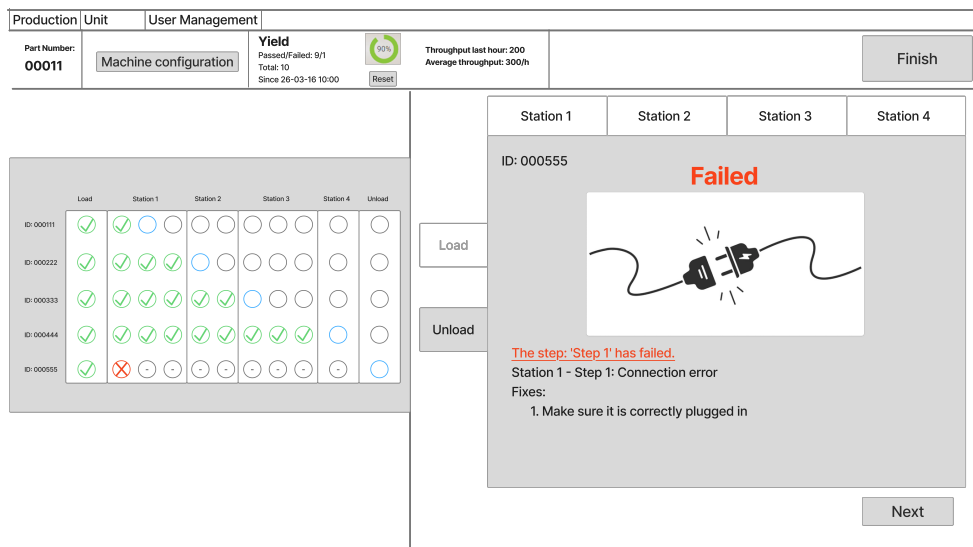


Figure 4.13 Failed step - Version B: Operator-oriented failure message

Additionally, the progress overview clearly indicates where the failure occurred, as well as subsequent steps, which were not executed, being represented with a grey border and dash inside.

4.2.1.5 Errors

During the prototyping process, additional information about the machine was provided by the supervisors. This led to a distinction between fails and errors. Fails are product related issues, referring to the actual unit, whereas errors are machine related and require different resolutions. Due to this, errors were introduced in the prototypes, as seen in Figure 4.14 and Figure 4.15. These error messages occur before unloading, similar to failures, but require different information. Since operators may need to take a picture of errors in order to send them to the company for assistance, the error messages should therefore include a call stack, as this information is useful for the developers.

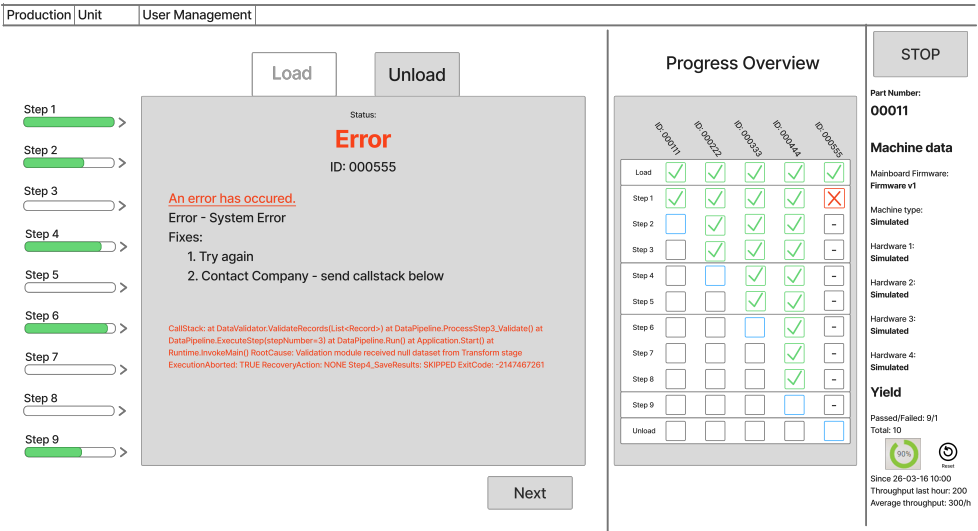


Figure 4.14 Machine related error - Version A: Diagnostic error message

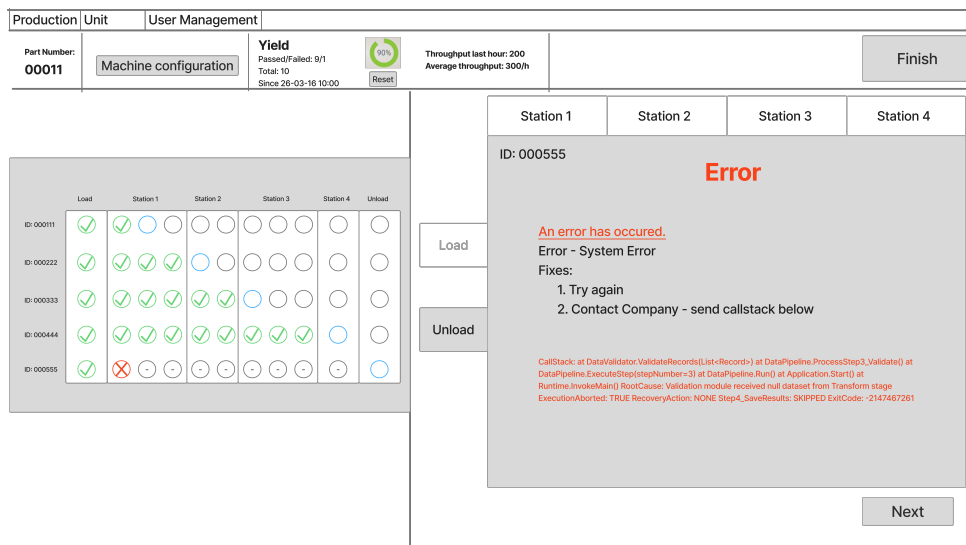


Figure 4.15 Machine related error - Version B: Diagnostic error message

4.3 Usability Testing Process

A usability test was conducted to validate and evaluate the design decisions made in the Lo-Fi prototypes. The purpose was to compare the two prototype versions in order to develop a finalized design based on user feedback, by combining the components from each version that users found most effective. The test sessions consisted of task-based scenarios, as well as an interview focusing on comparative questions.

4.3.1 Participants

A total of five participants participated in the Lo-Fi usability testing. Due to confidentiality constraints regarding the next generation machine, only employees at the company were selected. Furthermore, the selected participants were all from the same division responsible for the machine, therefore having knowledge of how the future machine is going to operate. This decision was made since the Lo-Fi test was conducted with the purpose of evaluating the design, layout, and usability, rather than functionality. The next generation machine involves complex functionalities that would otherwise require extensive explanation, which could shift the participant's focus away from design and layout, and instead toward understanding system behaviour.

4.3.2 Setup

The setup of the usability tests was similar to the initial usability testing, as described in Section 3.3.1.2. Each session took place in a conference room, using the same arrangement, and was recorded via Microsoft Teams.

However, no computer was used for the participants to interact with during these sessions. Instead, to better simulate a Lo-Fi experience, each view created in Figma was printed out as A3 papers, as seen in Figure 4.16, approximately the same size as the screens attached to the machines. As one facilitator introduced each scenario and its tasks, the other placed the corresponding printed view in front of the participant. This setup was used for early evaluation of design decisions without the influence of interactive functionality. For the post-test questions, one facilitator asked the questions, while the other acted as a note-taker. Each usability session lasted approximately 50-60 minutes.

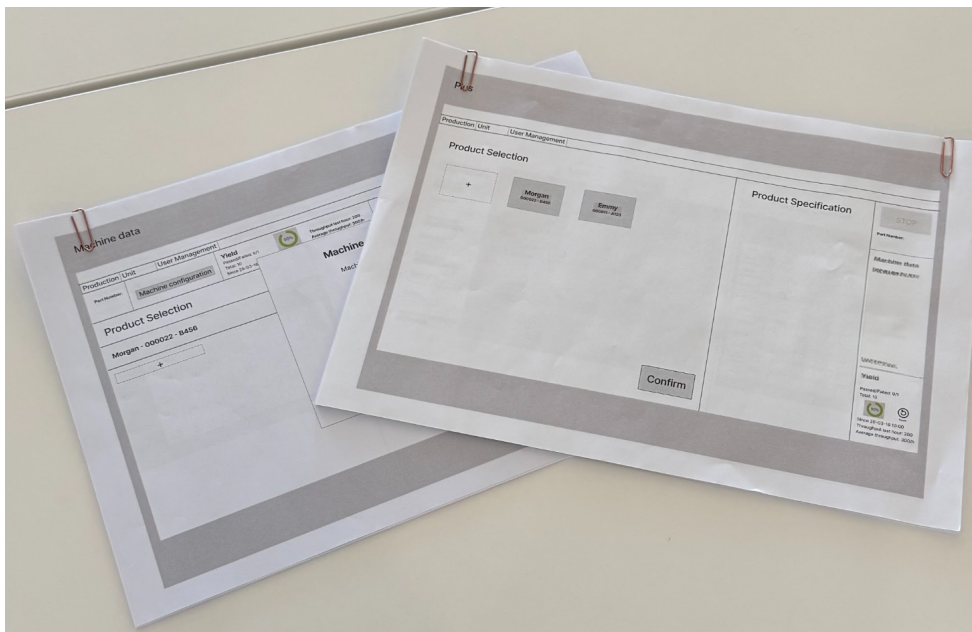


Figure 4.16 Paper-based Lo-Fi prototypes

4.3.3 Procedure

As in the previous testing procedure, each test participant received an invitation which included a consent form. At the beginning of each session, a short briefing was held to inform the participants about the structure of the session.

The first phase consisted of task-based scenarios. As two prototype versions were available, the order in which they were presented differed for each participant, to minimize order effects. The scenario began as the initial view from one of the two versions was placed in front of the participant. A task was then introduced, allowing the participant to interact with the paper prototype. After the participant completed an action, the next view was placed on top of the previous one to simulate a system transition. Once one version was completed, the second version was introduced, following the same scenario and set of tasks.

Following the task-based scenarios, participants were asked a set of post-test questions. These questions were structured around direct comparisons of specific components in the two versions, asking the participants which one they preferred. Participants were asked a total of 14 comparative questions, evaluating 14 components. In order to gather both quantitative and qualitative data, participants were asked to vote for their preferred version, as well as providing explanations for their choices.

4.4 Usability Testing Results

This section summarises the findings from the five Lo-Fi usability tests. The results include both qualitative insights derived from the affinity diagram analysis and quantitative observations based on participant feedback and preferences. Together, these findings provide a multifaceted understanding of how users interacted with the prototype and highlight key areas where the design supported or hindered usability.

4.4.1 Qualitative Results

To analyse the qualitative data from the Lo-Fi prototype tests, an affinity diagram approach was again applied. All participant comments and observations were first transcribed and coded into four categories: Positives, Negatives, Ideas, and Information. The coded statements were then organised by identifying recurring patterns and similarities across the material, allowing for a structured interpretation of how users understood and interacted with the prototype. Among these, the themes that proved most relevant for further development were those relating to Positives, Negatives, and Ideas. These themes, illustrated in Figure 4.17, form the basis for identifying which aspects of the design should be preserved, which require revision, and which represent potential opportunities for improvement in the next iteration of the prototype.

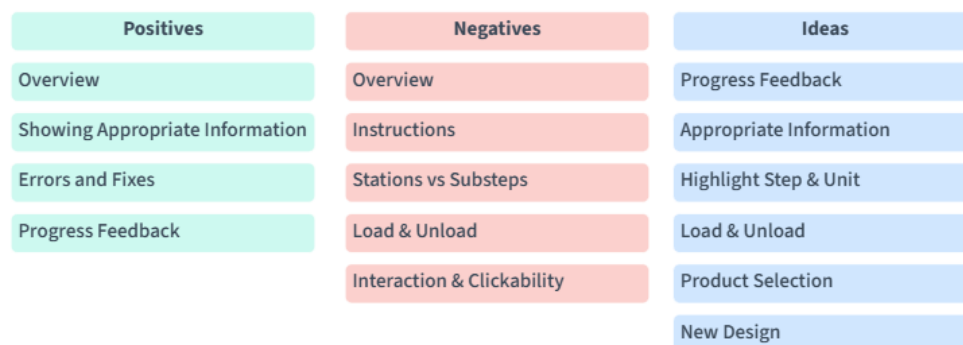


Figure 4.17 Lo-Fi: Affinity Diagram Themes

4.4.1.1 Results of the Affinity Diagram

The themes identified through this process provide insight into how users interpreted the prototypes and highlight both shared experiences and points where their understanding differed. The following section outlines these themes and summarises the key insights associated with each.

Positives

The Positives category captures aspects of the Lo-Fi prototype that participants experienced as clear and helpful. Two participants commented favourably on the introduced overview, describing it as a useful high-level representation of the workflow. Three of the participants also appreciated the prototype's effort to show only information relevant to the operator and the active step. This reduction of unnecessary detail helped users stay focused and made the workflow feel more manageable. Positive responses further emerged around the themes of errors and fixes. Although the prototype did not yet include fully functional error states, four of the participants reacted well to the concept of simplified error messages paired with actionable guidance, viewing this as an improvement over the more technical messages in the current system.

Finally, two participants highlighted the prototype's progress feedback as a helpful element. Examples included clearly indicating which step was currently being performed and explicitly showing when a step was ongoing. These cues suggest that progress related visual indicators can play a meaningful role in supporting user orientation throughout the process.

Negatives

The Negatives category reflects the aspects of the Lo-Fi prototype that caused uncertainty, confusion, or difficulty for participants. Although the overview was generally appreciated, three users found its current form unclear, particularly regarding how it

communicated which unit was positioned in front of the operator. Uncertainty also emerged around the instructions, especially those related to the fixes displayed after a fault. Two of the participants found the placement and timing of these instructions confusing, which made it challenging to determine what action was required and when it should be performed.

Another area of difficulty concerned the distinction between stations and substeps. Four participants struggled to understand which substeps belonged to which stations, making navigation especially confusing when encountering errors. This indicates that the structure and terminology of the workflow need to be made more explicit. Similar confusion was noted in relation to the load and unload steps. Three participants raised questions about the naming, placement, and navigation of these actions, indicating that their purpose and timing were not sufficiently clear.

Finally, three users pointed to issues with interaction and clickability. Due to the limited visual affordances of the Lo-Fi prototype, it was often difficult to recognise which elements were interactive. This highlights the need for more consistent and clear visual cues in future iterations to support intuitive interaction.

Ideas

The Ideas category reflects suggestions from participants that highlight opportunities to strengthen the next iteration of the interface. Two users proposed refinements to the prototype's progress feedback, such as removing the traditional progress bars and instead visualising progress in a way that more clearly reflects the movement of units through the workflow. Two of the participants also emphasised the importance of presenting appropriate information at the right moment. Suggestions included displaying fixes only when they are actionable, reducing the size of instructional images to make space for more relevant content and adding clearer titles to steps to support interpretation.

A recurring idea concerned the need to more distinctly highlight the active step and unit. Two users noted that stronger visual emphasis, such as clearer colour cues or structural indicators, would help them maintain orientation. Further suggestions were made regarding the load and unload steps. Four participants recommended merging these into a single main operator step, as the physical machine treats them as part of the same station. This consolidation was seen as a way to simplify navigation and align the digital workflow with the operator's real-world actions. Although product selection was not the primary focus of the test, two participants proposed improvements such as combining a search bar with a set of clickable letters for quicker navigation, as well as allowing the list of products to be sorted differently via a dedicated button.

Finally, a particularly insightful suggestion proposed a new design structure in which a top section could be used to switch between various menus while keeping the

main task view visible at all times. This idea introduces a promising direction for supporting multitasking and maintaining operator focus in future iterations of the interface.

4.4.2 Quantitative Results

The comparative questions at the end of the tests resulted in the preferences summarised in Table 4.1. Overall, several clear design preferences emerged, while other aspects remained inconclusive due to the lack of a strong majority among the five participants. For components where a clear preference was identified, these outcomes were directly reflected in the subsequent design iterations. In contrast, components with inconclusive results identify areas that require further consideration in the continued design work.

Table 4.1 Lo-Fi Prototype Design Preferences Summary

Component	Preference	Mentions
Start directly in Product Selection or have a Start Screen	Product Selection directly	4
Products in rows or boxes	Boxes	5
Plus button on the right or left	Right	5
Search field or clickable letters/numbers for sorting	Inconclusive	-
Product information on the right or integrated into the main screen	Inconclusive	-
Overview to the left or right of the main screen	Inconclusive	-
Overview vertical or horizontal	Inconclusive	-
Checkboxes or circles	Inconclusive	-
Present each substep or each station	Each substep	5
Load and Unload above or beside the main screen	Combine into one button	4
Progress bars or no progress bars	No progress bars	4
STOP or Finish	Inconclusive	-
Information panel on the right or above the main screen	Above	4
Machine data button or always visible	Inconclusive	-

Note: “-” indicates that responses were split and no clear preference was identified.

An example of a component with a clear preference is the placement of the load and unload functionality. Instead of preferring one of the presented alternatives, participants expressed a preference for combining these actions into a single button rather than separating them, which was also taken into account in the continued design work.

4.5 Second Lo-Fi Prototyping

The new-generation camera production machine is still in the early stages of development. As a result, while this project focuses on developing a proof-of-concept prototype for the interface, a parallel proof-of-concept project for the machine itself is also under development. Consequently, updated requirements were introduced after the Lo-Fi testing phase, which motivated the development of a second Lo-Fi iteration to incorporate these changes and refine the design based on user feedback and comparative results.

The most important new directive concerned the area where operators perform loading and unloading tasks. In the current camera production machine, both actions occur within the same hatch, which was also reflected in the first Lo-Fi version. However, it was later informed that the new machine will feature two separate hatches, one for loading and one for unloading.

4.5.1 Design

This subsection describes how the new directives and user feedback were translated into design changes in the second Lo-Fi iteration, focusing on layout adjustments and interaction refinements.

4.5.1.1 *Updated Layout*

Due to the loading and unloading areas being separated into two distinct hatches, adjusting the layout of the prototype to better leverage natural mapping was considered necessary. As the screen will be placed above the hatches on the machine, aligning the left side of the interface with the loading area and the right side with the unloading area creates a more intuitive mapping with the physical layout beneath, as shown in Figure 4.18 and enlarged in Figure A.7.

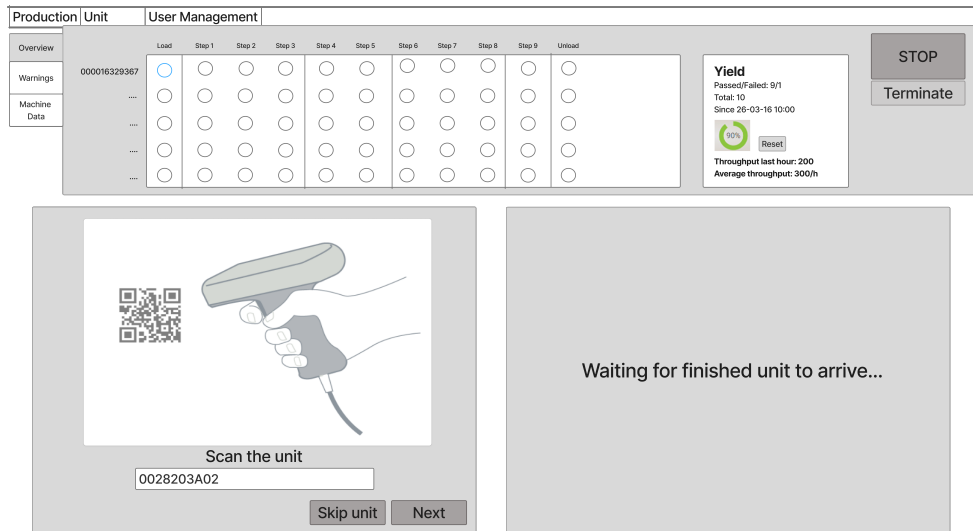


Figure 4.18 Updated layout of the process view supporting intuitive load and unload mapping

This change required moving the location of the progress overview, which is now positioned at the top of the interface and presented horizontally. As four out of five participants in the usability testing preferred the information panel to be placed at the top, this panel was therefore combined with the progress overview by presenting them as tabs. An additional change based on user feedback was to display each individual step in the overview, instead of grouping them as stations. Furthermore, a terminate button was introduced to the interface.

4.5.1.2 Step Status

The step status, as seen in both Figure 4.19 and Figure 4.20, is now displayed in the middle of the screen. The previous load and unload buttons have been combined into one, which functions as a “Back” button when viewing the step status. Figure 4.19 represents a successfully completed step, while Figure 4.20 represents a failed step. Additional information is also provided within the step status, including the completion time, the duration of the step, and the total duration for the entire station. Based on user feedback, fixes presented in the failed step status have been removed, as these fixes are not actionable until the full process is completed.

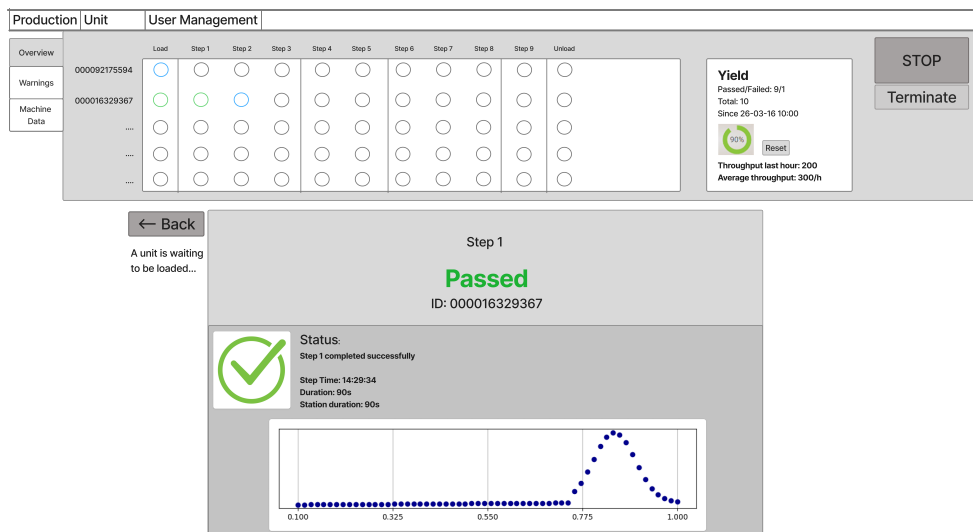


Figure 4.19 Updated step status showing a successfully completed step for a selected unit

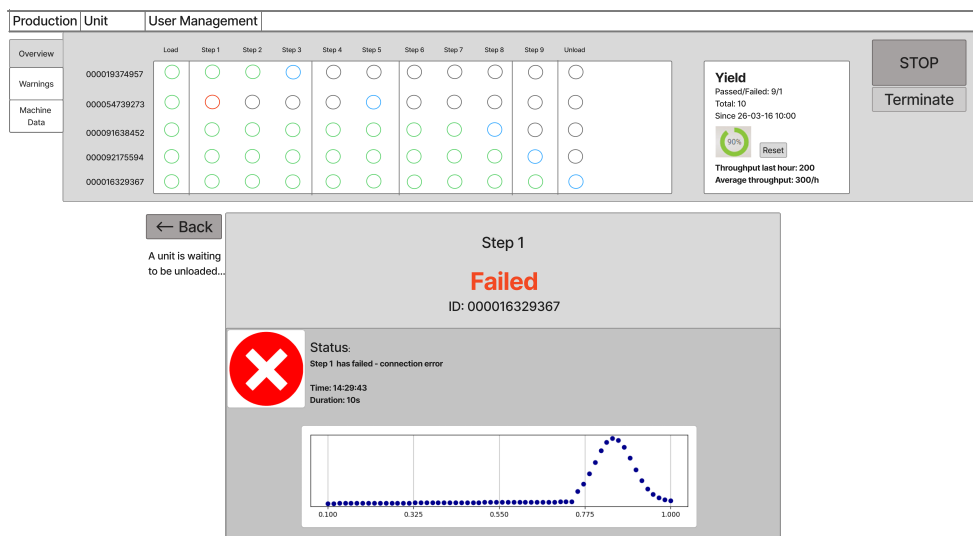


Figure 4.20 Updated step status showing a failed step for a selected unit

4.5.1.3 Unload

Figure 4.21 introduces the unload instructions for a successfully passed process, while Figure 4.22 represents a failed process. In the initial prototypes, the failed un-

load was divided into two separate pages, one for explaining the failure and another for unloading instructions. In this iteration, all information is presented on a single page. This change derived from user feedback and was made to provide operators with all relevant information in one place, in order to improve efficiency by reducing unnecessary navigation.

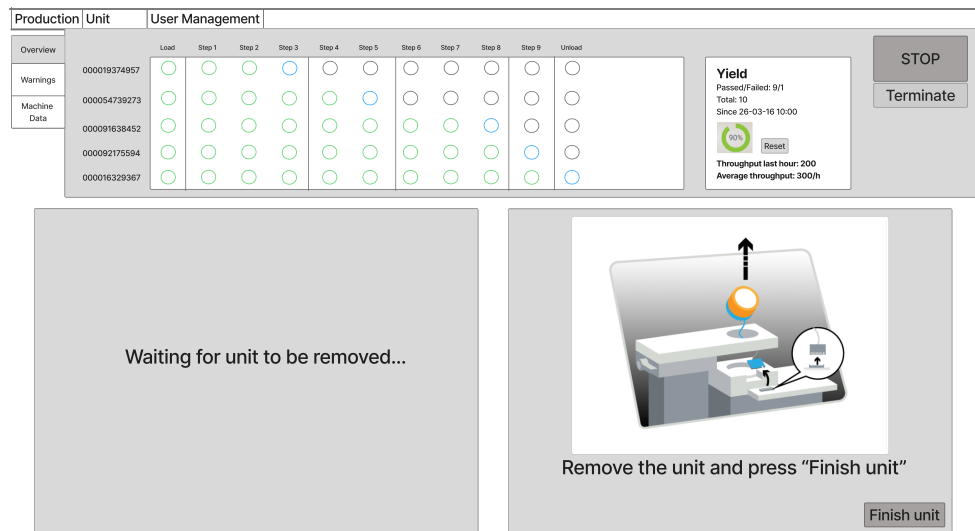


Figure 4.21 Updated unload view for a successfully processed unit

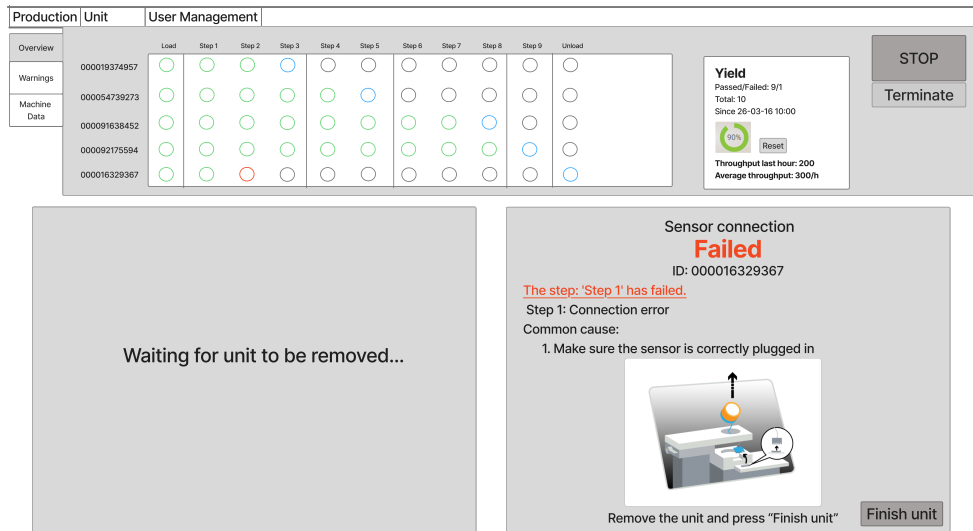


Figure 4.22 Updated unload view for a failed unit with integrated failure information

4.5.1.4 Alarms

An additional view for alarms was introduced in this iteration, as seen in Figure 4.23. The existing prototypes from the first iteration did not contain this view, as the alarms were not prioritized compared to the other functionalities. However, through further supervision, a clearer understanding of their importance within the system was achieved. This resulted in their inclusion in the second Lo-Fi iteration. A more detailed description of the alarm functionality is provided in the Hi-Fi chapter in Section 5.1.1.4.

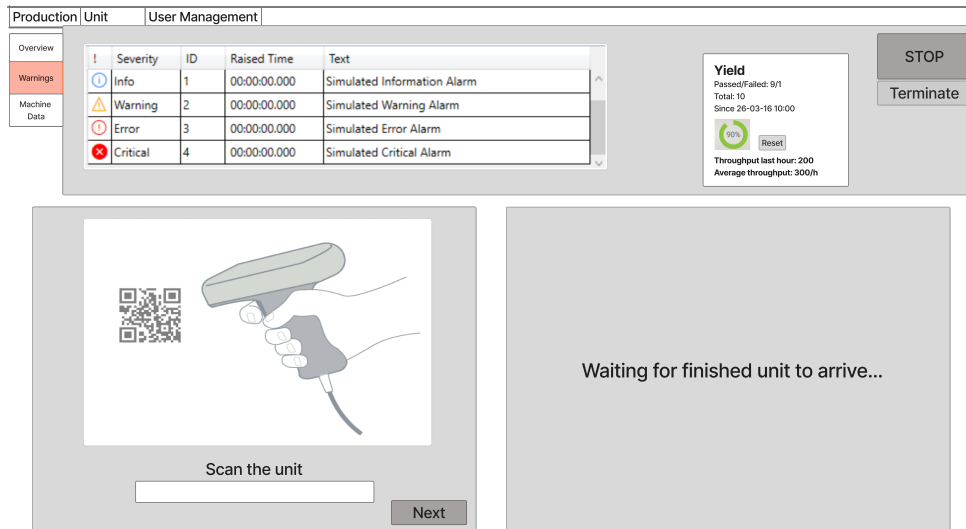


Figure 4.23 Early design concept of the Alarms view presenting machine-level alerts

4.5.2 Feedback

Since the second iteration Lo-Fi prototype was developed by combining the two prototypes from the first iteration, as well as incorporating new details derived from updated directives, it was considered necessary to gather additional feedback before proceeding to the development of the Hi-Fi prototype.

The feedback was obtained from both supervisors and two participants from the Lo-Fi usability testing. Unlike previous testing phases, the setup and procedure were less structured, as the new prototype was presented rather than actively tested. As each updated view was shown, participants were encouraged to share their thoughts continuously.

Overall, the feedback was largely positive, with no major changes suggested. The main points raised concerned minor adjustments, such as button placements and terminology. For instance, the “Skip unit” button was suggested to be relocated to the opposite side of the “Next” button to reduce the risk of accidental presses. Additionally, a change in terminology from “Warnings” to “Alarms” was suggested for one of the tabs in order to more accurately represent critical system events.

4.6 Key Takeaways

Several insights from both Lo-Fi iterations were identified to guide the development of the Hi-Fi prototype. These insights are based on user feedback gathered from the initial usability testing and the second iteration feedback sessions, as well as the updated directives.

Overall, the system was perceived as simple and intuitive, with participants appreciating the effort to show only relevant information. This aspect of the design should be maintained in the Hi-Fi prototype, as it supports an efficient workflow. The concept of the progress overview and the updated error messages were also highly admired. The improved clarity about where users are in the process, along with clearer messages, enhanced user understanding.

At the same time, certain areas for improvement were identified. Participants expressed uncertainty regarding which elements were interactive and clickable. This highlighted the need for clearer visual cues to distinguish clickable elements. Furthermore, maintaining a clear user orientation in the interface was seen as an important factor. Using visual indicators is necessary to show a user's position, for example when viewing a step status and identifying which unit it belongs to. Additionally, feedback indicated a need to further develop and explore the search function in the product selection process. This concerned both design and functionality, such as how products should be sorted and what the search bar should look like.

Moving into the Hi-Fi iteration, several aspects from the second Lo-Fi iteration should be carried forward. This includes the updated layout of presenting two hatches in the interface, aligning with the physical machine to support natural mapping and improve intuitiveness. Refinements in button placements to reduce the risk of accidental presses, as well as validations of terminology to better reflect system behaviour, should also continuously be considered to align with user expectations. Overall, the findings indicate a well-received design, with remaining improvements centered on enhancing interaction clarity, strengthening user orientation, and fine-tuning existing functionality.

5 High-Fidelity Design

This chapter describes the high-fidelity design phase, detailing the refinement of the final interface for the camera production machine. It covers the development of the Hi-Fi prototype, usability testing and results, and concludes with key takeaways highlighting validated design decisions and remaining improvement opportunities.

5.1 Final prototyping

Following the evaluation of the Lo-Fi prototypes, the next phase focused on developing a high-fidelity prototype of the interface. The purpose of the final prototyping stage was to refine interaction details, visual hierarchy and layout decisions while consolidating the most effective elements from the earlier design versions. This prototype was developed in a standard Figma design file, allowing more detailed interface components, visual styling and interaction states to be layered onto the established structural foundation.

5.1.1 Prototype

To support a more realistic and polished representation of the interface, several overarching design decisions were applied across the high-fidelity prototype. Rounded corners were introduced throughout the interface to create a more gentle visual expression, while still maintaining a professional and industrial character [14]. Additional small visual details, such as defined top and bottom sections and subtle spacing adjustments, were added to increase the perceived realism of the interface and better reflect how a final implemented system might appear.

Neutral colours were used for background and secondary elements to reduce visual noise, while more saturated colours were reserved for important actions and status indicators. This selective use of colour helps direct operator attention and supports clear and efficient interaction [9].

Unlike the Lo-Fi prototypes, the Hi-Fi version was also made partially interactive. Interface elements were implemented as clickable components, allowing users to navigate between views and interact with the prototype as if it were a functional system. This made it possible to run the prototype and experience flows and interactions in a more authentic manner.

Together, these refinements contribute to a cohesive and realistic prototype that balances visual refinement with functional clarity. These refinements were further guided by persona characteristics, particularly in balancing clarity and efficiency across different levels of user expertise.

5.1.1.1 Product Selection

The final version of the product selection view is shown in Figure 5.1 and closely resembles Version A of the Lo-Fi prototype, with only limited structural changes. The primary issue identified for this view, which was the difficulty of locating how to configure the product grid, was addressed by redesigning the associated button. The previously subtle button was replaced with a more explicit one labeled “Edit Product Grid”, accompanied by a commonly recognized edit icon, improving both visibility and clarity of purpose.

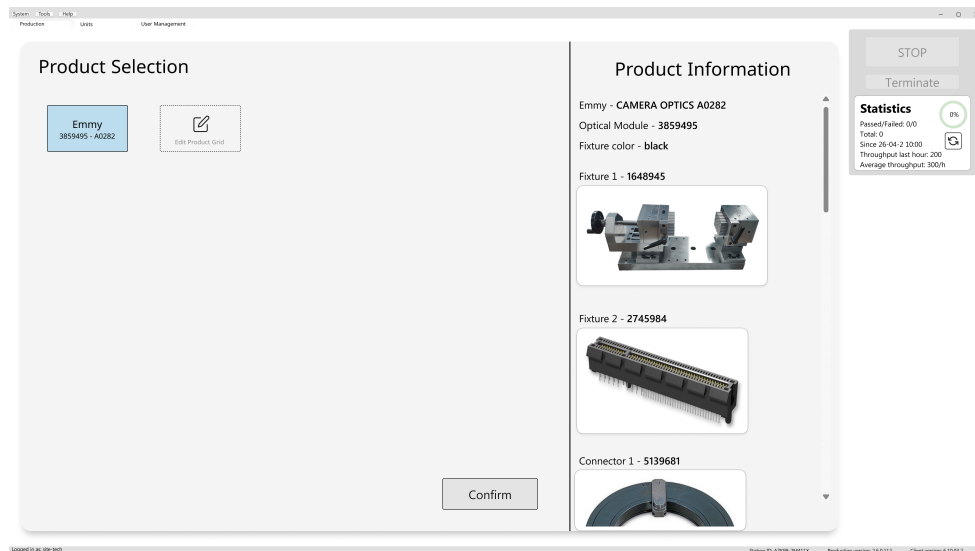


Figure 5.1 Hi-Fi: Product Selection

The most notable structural change concerns the placement of the machine data information. Instead of being permanently visible on the right side of the interface, this information has been moved into one of the tabs introduced in the second Lo-Fi version and becomes available once the user proceeds past the product selection phase. This adjustment reduces visual clutter in the main selection view while ensuring that machine related details remain accessible when needed.

The reason why the rest of the view remains very similar to Version A of the Lo-Fi prototype, as well as to the original interface, is that no significant negative feedback

was identified for this part of the design. Maintaining a familiar layout supports established usability principles of consistency, ensuring that users do not need to relearn functionality that already aligns with their expectations and mental models [10, 14].

The comparative question regarding the use of a search bar versus clickable letters or numbers for product sorting produced inconclusive results. For this reason, a combination of both approaches was implemented in the Hi-Fi prototype, as shown in Figure 5.2. The search bar provides an efficient method for locating products when a keyboard is available. However, since this is not always the case, two additional buttons for sorting products alphabetically and numerically were introduced. This solution represents a simplified alternative to clickable letters and numbers, while still supporting efficient navigation under varying interaction conditions, aligning with principles of flexibility and efficiency of use [14].

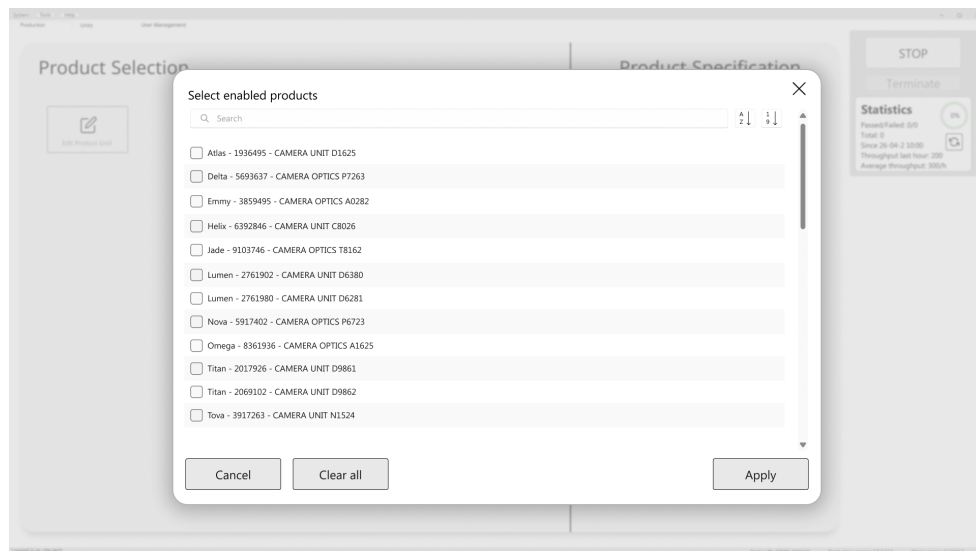


Figure 5.2 Hi-Fi: Product List

In this version, the product list is deliberately presented as a modal pop-up with a greyed-out background. This design choice constrains user interaction to the active window and prevents unintended interactions with background elements, supporting user control and reducing the risk of errors [10, 14]. In addition, the button used to deselect all checkboxes has been renamed from “Reset” to the more explicit label “Clear all,” better reflecting its actual function and reducing ambiguity for the user, in line with principles of clear and familiar terminology [10, 14].

5.1.1.2 Process

Building on the Lo-Fi evaluation, several refinements were made to the overall process view in the high-fidelity prototype, with the first process-related view shown in Figure 5.3 and enlarged in A.8. The main interaction area was refined to improve navigation clarity and consistency with established interaction patterns. The previously text-based “Next” action was replaced with a directional forward arrow symbol, reducing visual noise while retaining a familiar navigation cue. This approach aligns with the Machinery Directive’s recommendation that information presented on machinery should, where possible, rely on intuitive symbols rather than written text [7]. To further reinforce spatial consistency, the “Skip unit” action was moved to the left side of the interface to align with the existing “Back” interaction button in other views in the system. This alignment supports predictable navigation behaviour and reduces cognitive effort for operators [14].

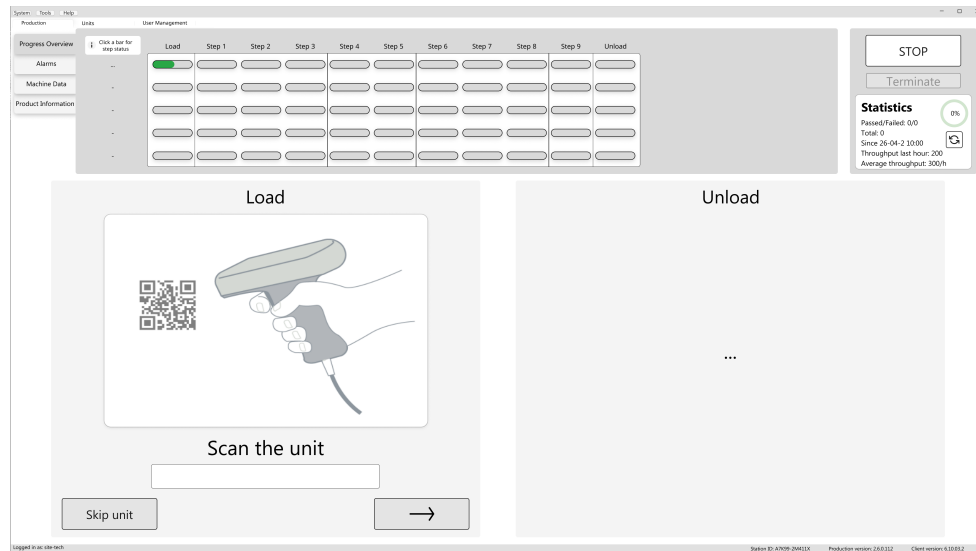


Figure 5.3 Hi-Fi: Process view with scan unit instruction

Clear Load and Unload titles were added above their respective sections to strengthen the mapping between on-screen actions and the corresponding physical locations. Rather than relying on explanatory text in areas not currently in focus, the ellipsis symbol (...) is now used to assign lower visual priority to non-essential information, making it easier for operators to concentrate on the active task [10, 14].

In the top section of the interface, elements with global relevance were grouped together to improve accessibility. The STOP and Terminate controls were moved

outside the tab section to ensure that critical machine actions remain available at all times. The information panel previously labeled Yield was renamed Statistics and positioned alongside these controls, reflecting that this information is not tied to a specific tab and may be valuable to monitor continuously [10, 14]. The visual representation of step progress within the Progress Overview tab was also refined. Circular indicators were replaced with more clearly clickable bar elements better suited for interaction, and the previous blue status indicator was replaced with a half-filled progress bar to more intuitively convey an ongoing step. To support discoverability, a lightweight information label stating “Click a bar for step status” was added above the progress overview, clarifying the interaction without introducing persistent instructional text [14].

Figure 5.4 shows the mounting stage of the loading process. Similar to the “Next” action, the “Back” navigation control is represented using a directional arrow symbol, establishing a consistent and immediately recognizable navigation pattern throughout the interface. In this view, the forward navigation action is labeled “Start” rather than “Next” to clearly indicate that a new process phase is initiated. This reduces ambiguity by making it explicit that the action triggers machine operation rather than simple screen navigation [10, 14]. Figure 5.4 shows the mounting stage of the loading process. Similar to the “Next” action, the “Back” navigation control is represented using a directional arrow symbol, establishing a consistent and immediately recognizable navigation pattern throughout the interface. In this view, the forward navigation action is labeled “Start” rather than “Next” to clearly indicate that a new process phase is initiated. This reduces ambiguity by making it explicit that the action triggers machine operation rather than simple screen navigation [10, 14].

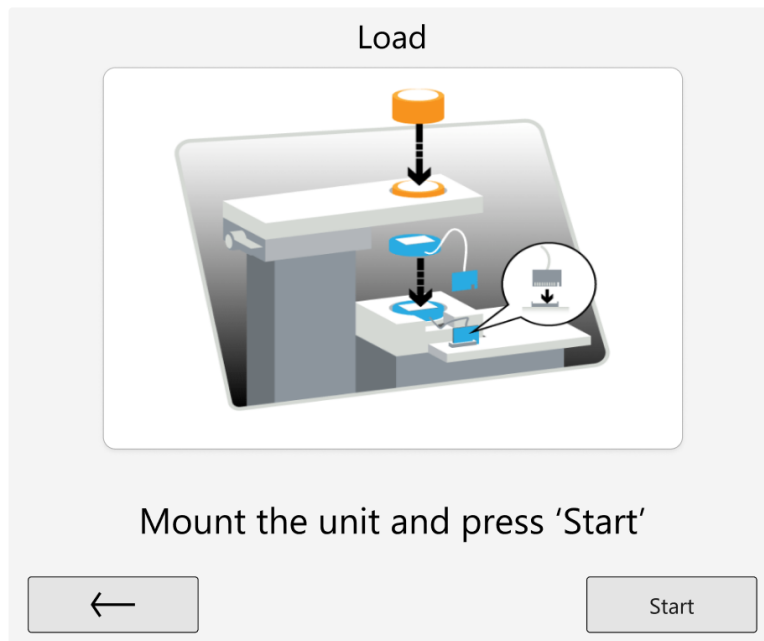


Figure 5.4 Hi-Fi: Load field with mount unit instruction

When the operator selects a specific unit that is currently performing a step in the machine, detailed status information for that unit is displayed in the main view, as shown in Figure 5.5. This includes step-specific durations as well as technical information describing how the operation is being executed.

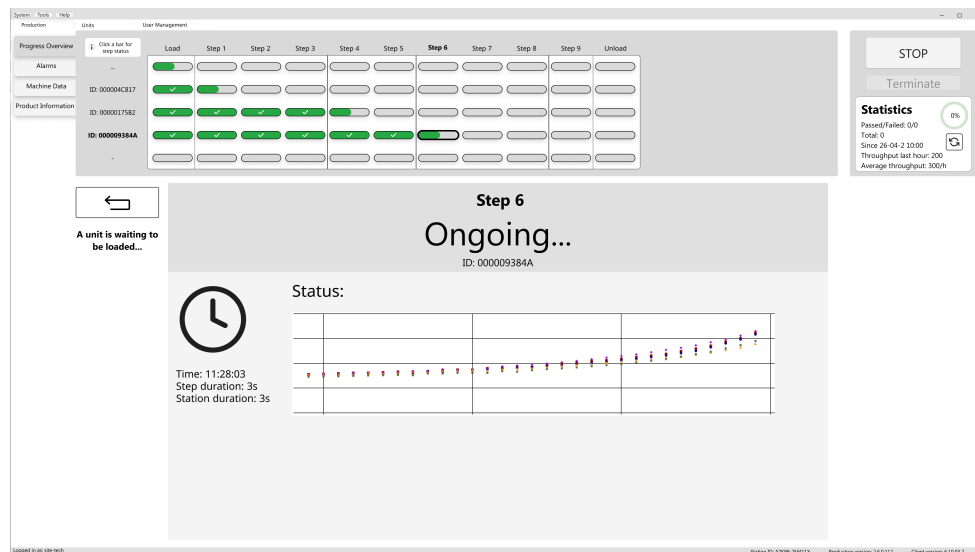


Figure 5.5 Hi-Fi: Ongoing step status

Progress is clearly communicated through the overview, where the selected unit is visually highlighted and shown at its current position in the process. The progress bar corresponding to the active step is emphasized through increased visual weight and both the step name and the unit ID are displayed in bold to reinforce which unit and operation are currently in focus. Navigation controls were also refined in this state. In line with earlier changes to the process view, an additional return-oriented symbol was introduced to clearly indicate that this action returns the operator to the previous activity, rather than initiating a new process step [10, 14].

Figure 5.6 illustrates the process state after the step shown in the previous view (Figure 5.5) has been completed. Completion is communicated by updating the status text from “Ongoing” to “Passed”, accompanied by a consistent visual transition in which relevant interface elements change from black to green. In addition, the progress bar for the completed step becomes fully filled and is marked with a checkmark. Together, these visual changes provide immediate and clear feedback that the step has been successfully completed, clearly distinguishing finished steps from those that are still pending or in progress [9, 14].

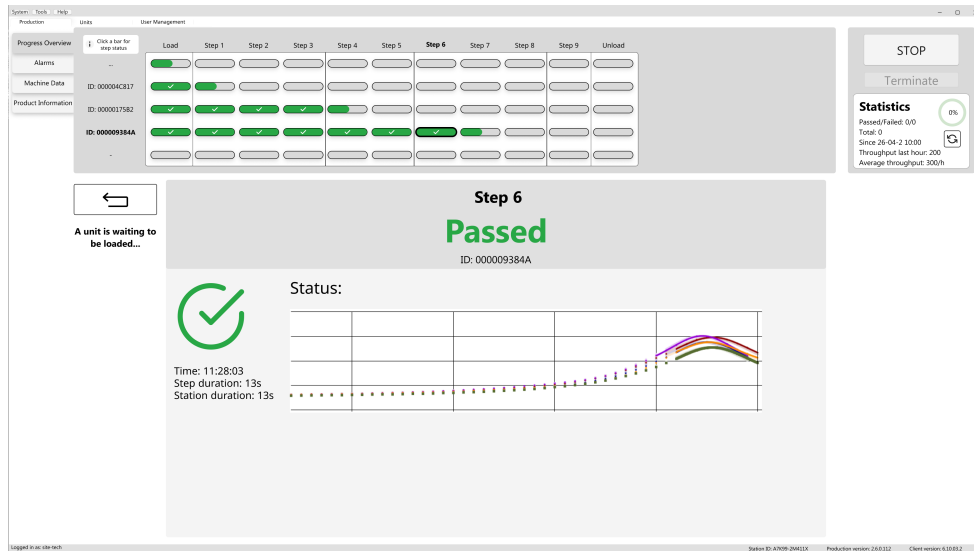


Figure 5.6 Hi-Fi: Passed step status

Figure 5.7 illustrates the process state after a unit has completed a full cycle through the machine and returned to the Load/Unload station, positioning the unit directly in front of the operator. In the progress overview, the unit is shown to have passed through all relevant steps, providing a clear and immediate visual confirmation that the process sequence has been completed.

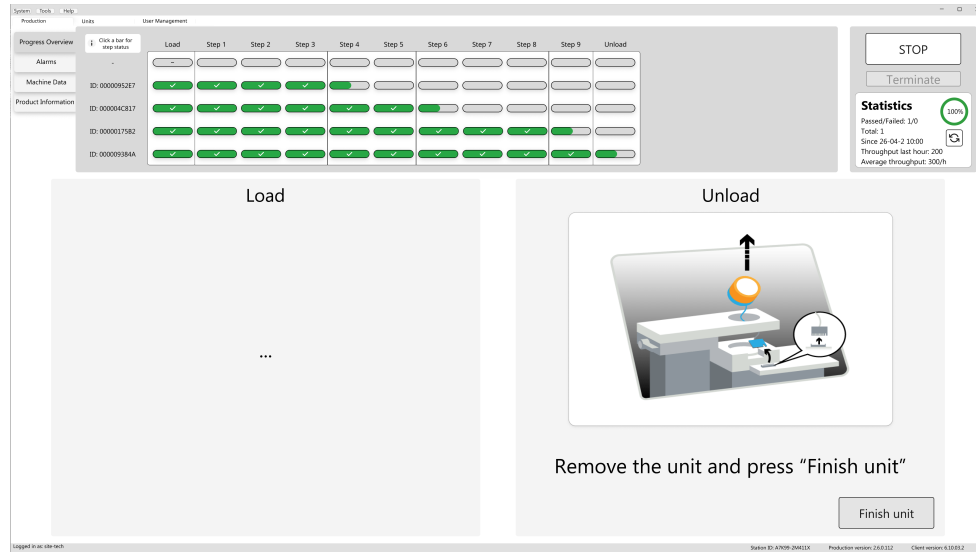


Figure 5.7 Hi-Fi: Process view with unload instruction

The horizontal marker (-) shown for the topmost unit in the progress overview indicates that the unit was previously skipped, corresponding to the “Skip unit” action available during loading, as shown in Figure 5.3. In addition, the Statistics panel is updated to reflect the completed cycle. Yield information is recalculated accordingly, providing immediate feedback on production outcome and ensuring that system-level performance metrics remain synchronized with the current process state [10, 14].

5.1.1.3 Fails & Errors

Building on the Lo-Fi evaluation, several refinements were made to the presentation of product-related failures in the high-fidelity prototype. Figure 5.8 shows the interface state when a unit has failed a step and the operator selects the corresponding unit in the progress overview to inspect the failure in more detail.

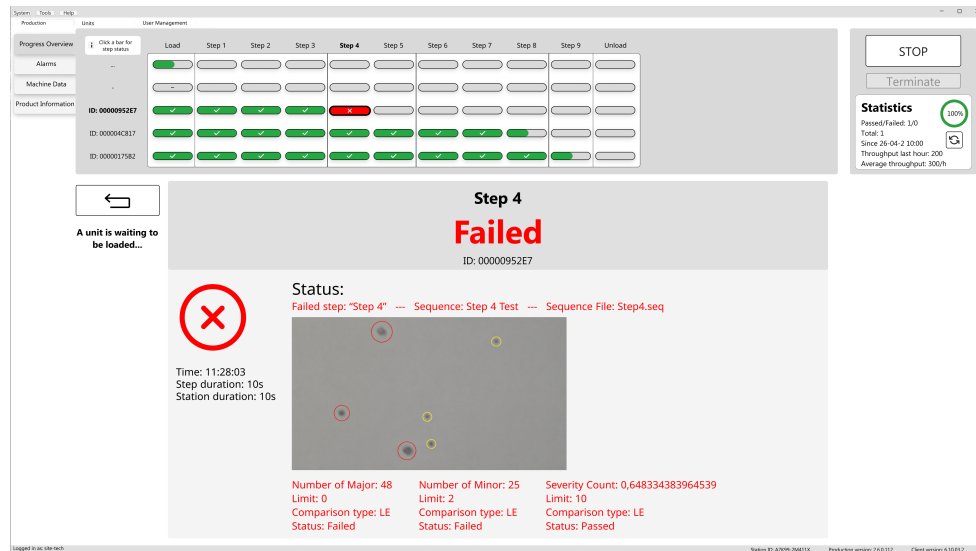


Figure 5.8 Hi-Fi: Failed step status

In this view, failure information for the selected unit is presented in the main display area. The use of red text, combined with a clear “Failed” status label and error iconography, is intended to make the presence of a failure immediately apparent and visually distinct from completed or ongoing steps. This strong visual contrast helps draw the operator’s attention to the error state and reduces the risk of overlooking critical information [9].

Step-specific failure details are displayed alongside the visual result, allowing the operator to identify both the location and nature of the fault. Direct access through the progress overview supports efficient and continuous fault diagnosis [10, 14]. To ensure the same level of visibility, system-level errors related to a specific unit are handled in the same way and are displayed in the main window, since such errors indicate unexpected behaviour that should not be overlooked by the operator. The key distinction is that system-level errors additionally include diagnostic information such as the call stack, to support reporting of unconventional issues to the company.

Figure 5.9 shows the interface state when a failed unit has completed a full cycle through the machine and returned to the Load/Unload station, positioning the unit directly in front of the operator. At this stage, the most critical information for the operator is presented as an overview, focusing on what has failed and what action needs to be taken next.

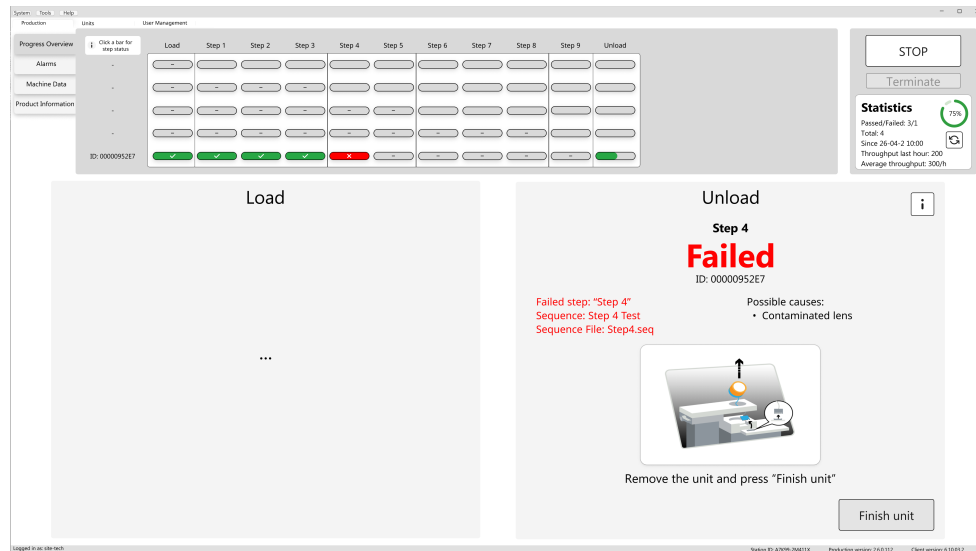


Figure 5.9 Hi-Fi: Process view with failed unit's unload instruction

The failed step is clearly highlighted with red status indicators, accompanied by a concise description of the failure and a list of possible causes. This allows operators to quickly assess the situation without leaving the main process context. For cases where additional technical detail is required, an information button is provided in the Unload section. This control allows the operator to navigate to a more detailed inspection view of the failure (Figure 5.8), ensuring that in-depth diagnostics remain accessible without overwhelming the primary workflow [10, 14].

5.1.1.4 Tabs

In addition to the process view, the interface includes several tabs that provide system-level information and controls, beginning with the Alarms tab that presents messages related to machine state and events that may affect production. Figure 5.10 shows an example of the Alarms view when a physical emergency stop has been activated during an active session.

ID	Severity	Raised Time	Text
4	Critical	11:06:9.456	Emergency stop active

Figure 5.10 Hi-Fi: Active Alarms tab

The Alarms tab functions as a centralized overview of machine-generated messages with varying levels of severity. Alarms range from informational messages and warnings that typically do not require operator intervention, to errors and critical alarms that indicate conditions which may affect machine safety, production continuity or operator safety. Each alarm is displayed with a severity indicator, timestamp and descriptive text to support rapid interpretation.

More urgent alarm conditions require explicit operator action before the machine can be resumed. In the example shown in Figure 5.10, the alarm cause “Emergency stop active” is displayed in bold, indicating that the condition is currently active and must be resolved. As long as this condition persists, action buttons for resuming operation remain disabled, preventing the operator from continuing the process prematurely.

To ensure that critical situations are not overlooked, the interface automatically switches to the Alarms tab when an Error or Critical alarm is raised. This behaviour interrupts the ongoing workflow and directs the operator’s attention to the alarm condition, ensuring that necessary corrective actions are taken before production can continue. This structured handling of alarms ensures that critical system states are clearly conveyed to the operator and that unsafe continuation of the process is prevented, supporting both effective prioritization and safe machine operation [10, 14].

Figure 5.11 shows the Machine Data tab, which presents configuration and system information about the machine, including hardware components, firmware versions and relevant technical parameters. This view is primarily intended for site technicians and company engineers, supporting tasks such as verification, troubleshooting, and system diagnostics. By separating machine configuration data from process-focused views, the interface keeps technical information accessible without interfering with everyday operator workflows [10, 14].

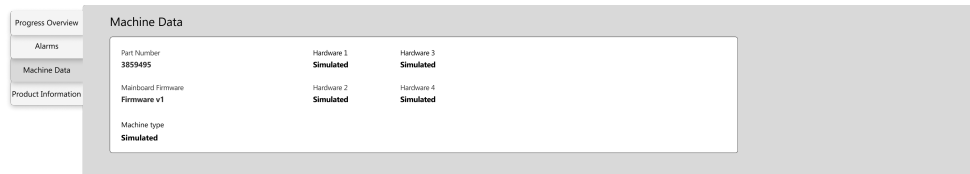


Figure 5.11 Hi-Fi: Machine Data tab

Figure 5.12 shows the Product Information tab, which presents product-specific details and visual references for the currently selected unit. Providing this information in a dedicated view supports manual adjustments and verification tasks when needed, while keeping the main process flow uncluttered and focused [10, 14].



Figure 5.12 Hi-Fi: Product Information tab

5.2 Usability Testing Process

To evaluate the Hi-Fi prototype and the final design decisions, a usability test was conducted. The purpose of this test was to validate the final prototype and identify any remaining changes required, as well as assessing the usability and overall user experience of the system interface. This marked the final stage of the thesis, concluding and evaluating the outcomes of the overall design process.

5.2.1 Participants

The usability test was conducted with a total of eight participants. A different group of participants was used for the Hi-Fi usability testing, meaning that none of the participants had taken part in the previous usability tests. As in the Lo-Fi usability test, and due to confidentiality constraints, the Hi-Fi tests were performed exclusively on employees from the company. In order to compare the new camera production machine with the current system, the same number of participants was used as in the pre-study usability tests. Since SUS scores were to be compared, maintaining an equal number of participants ensured a fair comparison.

Furthermore, to support fair comparisons, participants with varying levels of expertise were included, as described in Section 3.3.1.1. Although the new-generation machine system was unfamiliar to all participants, prior familiarity with the current machine was expected to provide an advantage, as participants could draw on existing knowledge of workflows and system objectives to complete tasks easier. Therefore, the same four-level scale for capturing differences in familiarity with the current machine was applied, based on a background assessment of participants' experience and work tasks. The distribution of expertise levels among participants is presented in Figure 5.13.

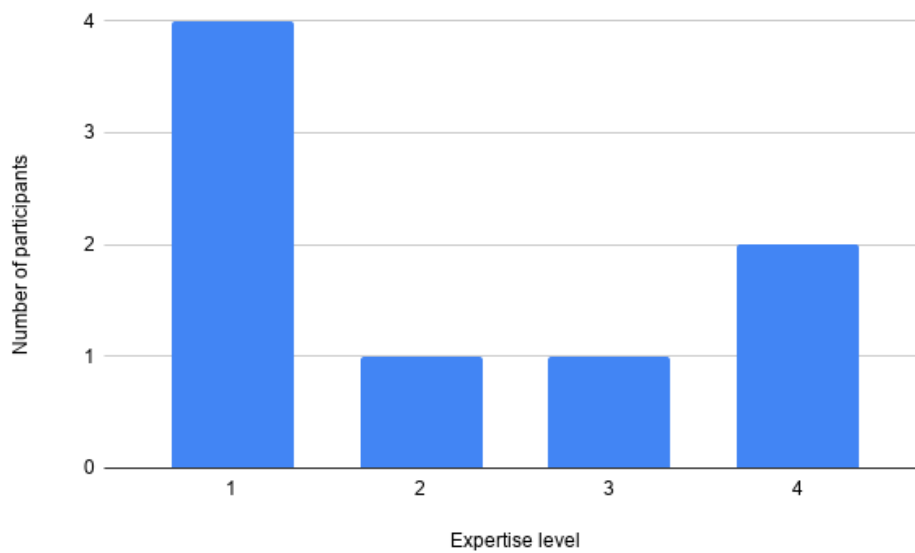


Figure 5.13 Hi-Fi: Participants by expertise level

The participant pool covered the full expertise scale, ranging from level 1 to level 4, with an average expertise level of approximately 2.1. Four of the eight participants were classified at level 1. These participants all held the role of Student Worker, indicating no prior experience with either the current machine or camera production systems. The remaining four participants held roles ranging from software engineer to Product Owner and therefore possessed relevant technical knowledge and experience. Participants' ages ranged from 23 to 53 years, with an average age of 30.3 years and a standard deviation of 9.7 years.

5.2.2 Setup

The Hi-Fi test followed a similar setup to the one described in Section 3.3.1.2. The sessions took place in a conference room, where participants were seated between the facilitators in front of a touch screen. Next to the screen was a paper cutout representing the five-unit slot turntable inside the machine, as well as the two hatches that operators interact with during operation. Paper clips were used to represent units being loaded into and unloaded from the hatches, as illustrated in Figure 5.14.

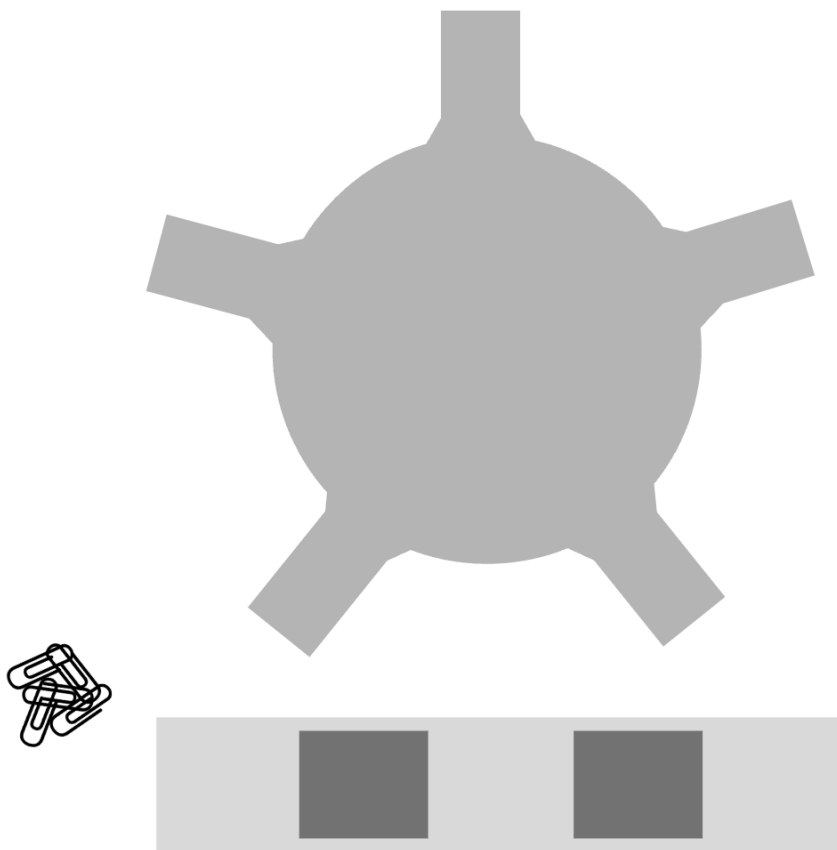


Figure 5.14 Paper cutout for Hi-Fi tests

Using a paper cutout of the machine served to simulate the internal processes occurring within the system as participants interacted with the interface. The new machine, using five unit slots, increases the complexity, as operators are required to track a greater number of units. Therefore, the use of a physical representation of machine movements was intended to support participants' understanding throughout the usability tests.

Participants were instructed to assume the role of operators, as their responsibility was to operate the two hatches by placing and removing paper-clips when instructed by the interface. The turntable was manipulated by one of the facilitators to simulate internal machine operations, while the other facilitator introduced the test scenarios. Additionally, one facilitator conducted the pre- and post-test interview, while the other acted as a note-taker. Each test session lasted approximately 20-45 minutes.

5.2.3 Procedure

The procedure of the Hi-Fi usability test session was identical to the one described in Section 3.3.1.3. As participants arrived to the session, an introduction took place where background information about the machine, an overview of the procedure, and facilitator roles were explained. Participants were also asked to give their consent in accordance with the consent form that was sent out beforehand.

The first phase of the test session consisted of a brief pre-test interview, during which participants were asked about their prior knowledge of the current camera production machine. This information was necessary to determine the expertise level of each participant, consistent with the approach used in the initial pre-study usability testing.

Following the pre-test interview, the second phase consisted of three task-based scenarios, in which participants interacted with the digital prototype while simultaneously operating the paper cutout machine. As in previous testing sessions, participants were encouraged to think aloud and describe their thought processes throughout the tasks.

Scenario 1

The first scenario required participants to select a product and then load the machine with units until one unit was unloaded. The scenario was considered complete when the first loaded unit had run a successful process and was removed. The purpose of this scenario was to allow participants to experience a full operational cycle for a unit from start to finish and get familiar with the workflow of the system.

Scenario 2

In the second scenario, participants were instructed to run another unit. However, during the process, a failure was introduced for one of the units inside the machine.

Participants were asked to identify and assess the failure, before being instructed to skip loading subsequent units until the failed unit had been unloaded. The scenario was completed when the failed unit had been removed from the machine. This task was conducted to expose participants to a failure and evaluate how they encountered them.

Scenario 3

The final scenario focused on interaction with the remaining tabs described in Section 5.1.1.4. Participants were instructed to load a new unit, but before doing so, an alarm was triggered, simulating the activation of the physical emergency stop. Participants were then required to navigate through resolving the alarm. Following this, they were asked to locate machine configuration information, requiring them to find the machine data tab. The same instruction was then given to finding information about the product used, that is the product information tab. Finally, participants were instructed to stop the machine. The purpose of this scenario was to evaluate how participants handled the alarm, navigated between tabs, and stopped the machine.

In the third phase, participants were asked to complete a SUS questionnaire. Participants were instructed to complete the questionnaire independently and at their own pace.

The final phase consisted of a semi-structured post-test interview aimed at gathering qualitative reflections. To enable comparison between the Hi-Fi prototype and the current camera production interface, the same set of questions were asked as in Section 3.3.1.3. The questions focused on overall experience, aspects that worked well or poorly, whether any information was perceived as excessive or insufficient, and thoughts on system failures. In addition, one question addressed the progress overview, focusing on its concept and design.

5.3 Usability Testing Results

This section presents the findings from the eight usability tests regarding the Hi-Fi prototype. The results are based on observations from the usability tests and the accompanying SUS responses, enabling both qualitative and quantitative analysis of usability.

5.3.1 Affinity Diagram

Qualitative observations from the Hi-Fi usability tests were analysed using the same affinity diagram approach as in the Lo-Fi evaluation, focusing on the categories Positives, Negatives and Suggestions. These themes form the basis for identifying val-

dated design decisions, remaining usability issues and directions for further refinement, as illustrated in Figure 5.15 and enlarged in A.9.

Positives	Negatives	Suggestions
Easy fault identification	Unclear product confirmation	Progress Overview improvements
Appropriate level of information	Unclear terminology and naming	Failure pop-ups for clearer feedback
Relevant failure details	Excessive technical information	Progress bar improvements
Simple design	Unclear Progress Overview elements	Improvements to the main view
Clear mapping and intuitive symbols	Insufficient guidance on alarm resolution	Clear alarm handling instructions
Progress overview	Missing information in remove field	Changes to terminology
Accessible product and machine information	Too small elements	
	Inconsistent design	
	STOP button distracts in Alarms	

Figure 5.15 Hi-Fi: Affinity Diagram Themes

5.3.1.1 Results of the Affinity Diagram

The following section outlines the identified themes and summarises the key insights associated with each.

Positives

The Positives category captures aspects of the Hi-Fi prototype that participants perceived as clear, effective and supportive of their workflow. One of the most frequently mentioned strengths was the overall simplicity of the design. All of the eight participants described the interface as either clean, intuitive or easy to navigate, as it felt familiar in a way.

Participants also responded positively to how faults and system states were communicated. Four users highlighted that faults were easy to identify and five appreciated the availability of relevant failure details. These details helped clarify both the source and location of failures. In addition, four participants emphasized that the amount of information shown was generally appropriate, as it focused on what was relevant to the current step and the appropriate instructions.

Progress feedback was another well-received aspect of the Hi-Fi prototype. Six participants described the progress overview as helpful for maintaining orientation, especially when multiple units were being processed simultaneously. Closely related to this, three users highlighted that clear spatial mapping and intuitive symbols made

the interface feel natural and predictable. Finally, three participants valued the ability to access and revisit product and machine information when needed.

Negatives

The Negatives category reflects areas of the Hi-Fi prototype that caused confusion and hesitation among participants. One recurring issue concerned product selection. Three participants were confused by the need to explicitly select and confirm a product before execution, suggesting that the system's behaviour did not align with users' expected workflow. Terminology and naming conventions also caused difficulties. Four users pointed out that some labels and technical terms were unclear or unfamiliar, which made it harder to interpret certain buttons or information. Related to this, three participants felt that some views contained excessive technical information, especially for a typical operator role, reducing clarity rather than improving understanding.

Despite generally positive feedback on the progress overview, five participants reported issues with specific elements. In particular, dynamically shifting units, unclear progress states, and reliance on colour cues reduced clarity and made the overview difficult to interpret, especially during error situations. Alarm handling emerged as another major challenge. Five participants felt that the interface did not provide sufficient guidance on how to actually resolve alarms, leaving them unsure of what actions to take for a few seconds. Adding to this uncertainty, two users noted that the STOP button drew disproportionate attention during alarm situations, creating confusion about whether stopping the machine or resolving the alarm should be the primary action.

Two users reported that the unload step lacked clear information about pass and fail status, making it difficult to determine which unit was being removed and whether it had successfully passed or failed. Finally, additional usability concerns included the size and consistency of interface elements. Three participants mentioned that some interactive elements were too small, making them easy to miss, while two identified inconsistencies in design and button behaviour that reduced predictability.

Suggestions

The Suggestions category captures participant ideas for improving future iterations of the interface. A central theme concerned improvements to the progress overview, raised by four users. Suggestions included enlarging the progress overview to reduce eye movement, repositioning contextual information panels and introducing a small, dedicated window with simplified alarm symbols to display common and minor alarms. Two participants also specifically proposed refinements to the progress bars, such as making state changes clearer or adjusting their visual behaviour to better reflect system status.

Another set of suggestions focused on improving feedback during failures. Two users recommended introducing clearer failure pop-ups to immediately communicate what went wrong and what action is required. Alarm handling was also a focus area, with four participants calling for clearer and more explicit instructions that guide the operator through alarm resolution in a structured way.

Improvements to the main view were suggested by four participants, who recommended stronger visual cues to guide attention, including highlighting relevant actions, greying out unavailable options and clearly marking passed units during unload. Lastly, two users proposed changes to terminology to make labels clearer and more intuitive for operators.

5.3.2 System Usability Scale

The SUS questionnaire was used to obtain a quantitative assessment of how participants evaluated the usability of the Hi-Fi prototype. Individual SUS scores, the average score, and the commonly referenced usability threshold of 68 are shown in Figure 5.16. Scores ranged from 70 to 95, indicating consistently positive usability perceptions across all participants. The average SUS score was approximately 83.4, placing the Hi-Fi prototype well above both the threshold for good usability and the existing camera production interface.

SUS Score Evaluation

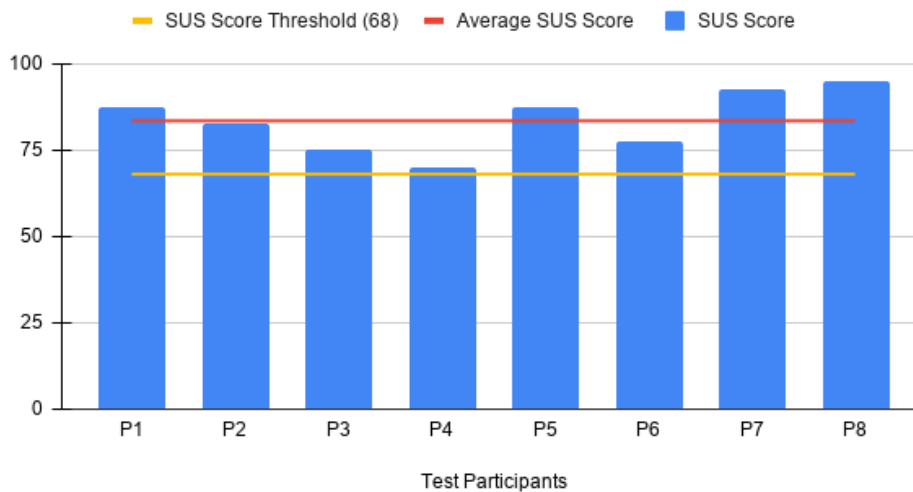


Figure 5.16 Hi-Fi: SUS scores with mean and threshold

All eight participants rated the prototype at or above the threshold value, with several scores falling within the range typically associated with excellent usability. Compared to the existing interface evaluation, the Hi-Fi testing results show a substantially reduced spread of scores, indicating a more consistent user experience and fewer outlier perceptions of low usability. However, there was an observable pattern suggesting that participants' level of expertise influenced how they evaluated the prototype. The Student Worker group of participants (P1, P5, P7, P8), who had the expertise level 1, produced an average SUS score of 90.6.

In contrast, the more experienced participants (P2-P4, P6), with an average expertise level of 3.3, representing a midpoint between moderate and high experience, rated the system significantly lower, with an average SUS score of 76.3. While this score still falls within the range of good usability, the difference suggests that more experienced users may have evaluated the interface more critically, potentially drawing on prior experience with similar systems. Although the sample size is small, this pattern indicates a tentative relationship between user expertise and perceived usability, where less experienced users may be more easily satisfied, while experienced users hold higher expectations regarding system behaviour and efficiency.

Overall, the SUS results indicate a substantial improvement in perceived usability between the already existing interface and Hi-Fi prototype's one. The combination of high average scores and low variation across participants suggests that the Hi-Fi prototype provides a more robust and accessible user experience, supporting the effectiveness of the design decisions implemented in this iteration.

5.4 Key Takeaways

The Hi-Fi evaluation confirms that the design refinements introduced after the Lo-Fi iterations resulted in a substantially improved and well-received interface. Both the qualitative findings and the SUS results indicate that the Hi-Fi prototype achieved a high level of usability, with participants consistently describing the system as clear, intuitive, and supportive of the operator workflow. The high average SUS score and reduced variation across participants suggest that the finalized design provides a robust and consistent user experience.

Several design decisions were strongly validated. The simplified and visually clean design, combined with a focused presentation of relevant information, effectively supported user orientation and task execution. The progress overview, spatial mapping between the interface and the physical machine and improved presentation of failures were particularly appreciated, reinforcing the importance of clear visual feedback and consistency with real-world machine behaviour. Accessible product and machine information was also valued, especially the ability to revisit this information beyond initial setup.

At the same time, the evaluation revealed remaining usability challenges. These primarily concerned clarity rather than fundamental design flaws. Issues related to terminology, alarm handling and the progress overview indicate that even in a high-fidelity and largely successful prototype, small ambiguities can affect user confidence, especially in critical situations such as alarms or handling failed units. Feedback from more experienced users further suggests that expertise influences expectations and critical evaluation of the system.

The suggestions collected during the Hi-Fi testing highlight opportunities for further refinement rather than major redesign. Participants primarily proposed enhancements to visual emphasis, attention guidance and instructional clarity, particularly in relation to alarms and progress feedback. While these improvements fall outside the scope of the current project, they provide clear direction for future development should the system be taken forward.

Overall, the findings demonstrate that the Hi-Fi prototype successfully addresses the core usability goals of the project. The design decisions implemented in this final iteration are largely validated by usability testing, with remaining insights serving as recommendations for future enhancements beyond the scope of this thesis.

6 Discussion

This chapter discusses the design process, evaluates the usability testing and final prototype, and outlines the limitations encountered throughout the process. It also addresses the research questions and explores opportunities for future work.

6.1 Design Process

The purpose of this thesis was to develop a proof-of-concept for a new-generation camera production machine. Since an interface already existed for the current machine, the design process began with a pre-study evaluation of the existing interface.

The pre-study phase played a crucial role in creating an informed foundation for the design process and development of the proof-of-concept interface. By analysing the system through heuristic evaluations and usability testing, a more structured understanding of system complexity, operator workflows, and recurring usability issues was established. This made it possible to identify and discover requirements to ensure that the final design addressed relevant user needs and practical constraints.

The personas developed during the pre-study phase strengthened the foundation by capturing differences in user roles, technical expertise and interaction patterns. They served as a continuous reference throughout the design process guiding decisions on information presentation, terminology, and interaction complexity. This helped ensure the interface remained accessible to less experienced users while supporting the efficiency needs of more advanced users.

Their influence is reflected in the final design, where the balance between simplicity and functionality addresses diverse user needs. This is further supported by the Hi-Fi results, where differences in user evaluations indicate how the interface accommodates varying levels of experience. Without this initial phase, the design process would likely have been more exploratory and relied on assumptions rather than actual user needs. This ultimately would have increased the risk of straying away from critical aspects, leading to less grounded design decisions.

Additionally, combining different user research methods contributed to a variety of data types and broader perspectives, enabling insights from all identified user groups. However, the distribution of methods varied across end users. For example, operators participated exclusively through surveys rather than usability testing, despite

being the primary user group. To further strengthen the pre-study phase, deeper involvement of primary end users would allow for a more accurate representation and strengthen the findings.

The ideation phase, consisting of multiple brainstorming sessions, was structured into distinct categories of the system, enabling each part to be explored separately. This approach benefited the ideation process, as it became more manageable and focused on specific workflows and elements at a time, allowing for deeper exploration. One outcome of this phase was the progress overview. This concept emerged to better visualize the workflow and provide a clearer representation of process status. It was considered a valuable outcome, as it improved user understanding and navigation within the system.

The development of the initial Lo-Fi prototypes during the Lo-Fi phase enabled rapid prototyping focused on layouts and workflows, as well as some important design details. This phase made it easier to test multiple design approaches, including both designs that built on the current camera production interface and entirely new concepts. Despite the unexpected new directives following the Lo-Fi testing, the creation of an additional Lo-Fi iteration proved valuable and benefited the development of the Hi-Fi prototype, as it provided an additional opportunity to evaluate layouts and elements before finalizing decisions. One aspect that could strengthen the Lo-Fi phase would be to expand the sample size and diversity of test participants. This could provide a broader range of perspectives, which would be useful in the early stages of development.

The development of the Hi-Fi prototype enabled a more detailed and interactive design, providing deeper insights into how users operate and navigate the interface. Testing this prototype helped validate whether improvements informed by earlier phases translated into a more intuitive user experience. At the same time, the evaluation indicated that expanding the level of interactivity, such as incorporating additional system states and edge cases, could have supported a more comprehensive assessment of how the proof-of-concept performs under varied conditions and interactions.

Overall, the design process followed an iterative, user-centred approach that involved users at each stage and allowed findings from earlier phases to inform subsequent design decisions. Despite minor deviations from the initial schedule, the project progressed smoothly and was completed within the designated time frame. This structured progression contributed to a final design that is both grounded in real user needs and refined through continuous evaluation.

6.2 Usability Testing Evaluation

This section evaluates the usability testing procedures and design conducted throughout the project. It focuses on their effectiveness in capturing relevant user insights across all testing phases.

Participant Background and Demographic Data

At the beginning of each usability testing session, a set of background questions were asked to establish an understanding of the demographics and the participants' prior knowledge with the machine. This included questions regarding age, role and familiarity with the machine in order to assign participants to an expertise level. While this provided a useful overview of the participant group, a deeper and more detailed demographics profile could have contributed to a clearer understanding of user differences. However, due to company confidentiality policies, the collection of personal data was limited. Despite this, the collected data provided sufficient context to support comparisons across different expertise levels.

Use of Expertise Levels

The use of an expertise scale proved to be highly valuable throughout the project. It enabled a systematic approach to categorizing participants based on their prior knowledge and familiarity. This supported the analysis of results by allowing findings to be interpreted in relation to different levels of expertise. Furthermore, it emphasized the need for varying requirements of guidance and instructions during testing for different levels. The planning of the usability tests were therefore based on ensuring that all participants, regardless of expertise level, were provided with the necessary background information and instructions. Overall, the use of an expertise scale supported both the project design and the analysis, proving to be a useful approach.

Task and Scenario Design in Usability Testing

The structuring of tasks within scenarios was found to be an important factor in the flow of the usability testing sessions. Using multiple tasks within a single scenario, required participants to redirect their attention to receiving additional tasks and instructions, which could interrupt the natural interaction flow. Therefore, structuring scenarios with fewer tasks would support a smoother and more realistic user experience, allowing participants to interact with the system more independently.

These effects became evident when comparing the pre-study with the Hi-Fi testing sessions. The pre-study consisted of a larger number of scenarios with fewer tasks, allowing participants to engage with the system with minimal interruptions. In contrast, the Hi-Fi testing consisted of fewer scenarios but a greater number of incorporated tasks, as the limitations in the prototype's functionality required facilitators to guide participants through certain interactions. While this approach ensured that all key interactions were tested, it also introduced disruptions that may have influenced participants' overall experience of the system.

Differences Between Testing Phases

The Lo-Fi testing differed from the other testing phases, as it involved two paper-based prototypes, which were less representative of a fully interactive system. The scenarios were also designed to be more general and fast-paced than in the pre-study and Hi-Fi testing. As a result, participants interacted with the system in a less natural way compared to the digital prototypes used in both the previous and later stages. In addition, this phase included fewer participants, which led to a smaller but more focused set of perspectives. Despite these differences, the Lo-Fi testing fulfilled its intended purpose by supporting early exploration of design concepts before progressing to more refined prototypes, while also encouraging more open and honest feedback due to its simplified and low-fidelity nature.

Use and Limitations of the SUS Questionnaire

Using a SUS questionnaire served as the primary method for gathering quantitative data and enabling a comparison between the current interface and the proof-of-concept interface. While SUS offers a standardized way of assessing usability, it does not fully reflect all aspects of usability in complex industrial systems. Therefore, the SUS does not provide a fully credible score and should not be treated as a completely reliable result. Additionally, the limited number of eight participants is far too small a sample size to yield a completely conclusive result. However, using the SUS as a comparative tool between the current and new interface was considered valuable and effective. As the same questionnaire, sample size and a similar distribution of participant expertise were used, the results provided a stable foundation for drawing conclusions.

6.3 Design Evaluation

This section reflects on the final design outcome of the Hi-Fi prototype by combining the authors' own evaluation with an interpretation of the usability test results. The section discusses the perceived strengths of the final design, aspects that could have been approached differently, reasons behind participant responses and how the SUS results support the overall evaluation.

Reflection on the Final Design

The final Hi-Fi prototype represents a successful outcome of the iterative design process. Compared to both the existing interface and the Lo-Fi prototypes, the final design demonstrates clear improvements in structure, visual clarity and interaction consistency. The simplified layout and reduced visual clutter supported user orientation and task execution, while the progress overview provided a clear representation of process state and unit flow. In particular, the spatial mapping between the interface and the physical machine, refined in response to the updated system directives, together with the improved presentation of failures, aligned well with the project's initial goals of supporting operational awareness and user confidence.

The positive reception of these elements during the Hi-Fi evaluation, combined with consistently high SUS scores, indicates that several key design decisions were effective. Overall, the final prototype balances simplicity with necessary system complexity and presents a realistic interface solution suitable for production deployment.

Alternative Design Choices

Although the final design was largely well received, some aspects could have been explored further or approached differently. Alternative visual representations of the progress overview might have reduced remaining uncertainty related to dynamically moving units, while additional iterations focusing on terminology and alarm presentation could have improved clarity in critical situations. These considerations do not indicate fundamental design flaws, but rather reflect deliberate trade-offs made within the project scope.

Greater interactivity could also have been explored as a design strategy to encourage user exploration and understanding of system behaviour. For example, enabling access to all step statuses or extended product configuration options might have supported a deeper comprehension of the interface structure and information flow, potentially revealing further insights into user expectations.

Interpretation of Test Results

The qualitative usability test results reflect both the strengths and limitations of the final design. Many participants described the interface as intuitive and familiar, which may be attributed to its visual consistency and reliance on established interaction patterns and heuristics. Differences in responses between participant groups suggest that user background influenced how usability was perceived. More experienced participants tended to evaluate the interface more critically, likely due to higher expectations and prior exposure to similar systems and the existing one, while less experienced participants appeared more easily satisfied by the overall clarity and structure. These findings indicate that the interface was generally understandable, but that perceived usability is influenced by user expertise and expectations.

SUS Comparison and Validation

The SUS results provide quantitative support for the qualitative findings. The high average SUS score for the Hi-Fi prototype, together with the reduced variation across participants, indicates a substantial improvement compared to the existing interface. This improvement is reflected in the increase from an average SUS score of 59.1 for the existing system to 83.4 for the new interface. The consistency of the scores suggests that the final design offers a more stable and accessible user experience. While the limited sample size restricts statistical generalization, the SUS data reinforces the conclusion that the Hi-Fi prototype successfully met its usability objectives, achieving a score well above the commonly accepted usability threshold of 68 and representing a meaningful advancement over previous solutions.

Overall, the design evaluation demonstrates a strong alignment between qualitative feedback and quantitative SUS results. The final Hi-Fi prototype represents a clear improvement over the existing interface, with remaining issues primarily related to refinement and contextual expectations rather than core usability concerns.

6.4 Research Questions

The research questions are addressed below.

RQ1: What user needs and operational requirements should guide the design of a proof-of-concept interface for the new camera production system?

The design of the proof-of-concept interface should be guided by key user needs, including clear system feedback, dependable process orientation, and a strong sense of control when managing a complex, multi-unit production process. Iterative usability testing further highlighted the importance of immediate visibility of process state, clear differentiation between ongoing, completed, and failed steps, and strong spatial correspondence between the digital interface and the physical machine.

In addition to these user needs, several operational requirements were identified, including support for parallel unit handling, efficient and non-excessive fault identification, and clear communication of required operator actions. These findings align with established usability heuristics, such as visibility of system status, consistency and clear mapping, as well as with industrial interface standards that emphasise safe, predictable and comprehensible operator interaction. Together, these needs and requirements highlight the importance of structured information, consistent visual cues, and accessible status feedback in supporting effective decision-making in industrial settings.

RQ2: What design improvements and alterations can make the new user interface more intuitive and efficient to use?

The evaluation indicates that intuitive and efficient use is supported by simplifying the visual structure, reducing unnecessary information and strengthening consistency across interaction elements. Design improvements such as a cleaner layout, clearer navigation symbols and consistent button behaviour contributed to improved usability. The progress overview played a key role in maintaining orientation, while the use of visual emphasis and clear status indicators supported the interpretation of ongoing, completed and failed steps.

In addition, clear terminology, structured alarm guidance and strong visual cues for critical actions were essential in supporting predictable interaction and efficient operator workflows. At the same time, retaining similarities to the existing interface was found to be beneficial, as familiar layout patterns and interactions reduced the learning threshold and helped users adapt more quickly to the new system.

RQ3: How do users perceive the created user interface prototype compared to the existing camera production system interface?

Users generally perceived the Hi-Fi prototype as a substantial improvement over the existing camera production system interface. This perception was reflected in both qualitative feedback, where participants described the interface as clearer and more intuitive, and in the quantitative SUS results, which showed a significant increase in average usability score. While less experienced users expressed particularly positive responses, more experienced participants tended to evaluate the system more critically, often reflecting higher expectations shaped by prior experience. Despite these differences, all participants rated the prototype above the accepted usability threshold, indicating broad agreement that the new interface provides a clearer, more consistent, and more intuitive interaction experience than the existing system, even though it is considerably more complex in terms of functionality and interaction design.

6.5 Limitations

As with any design-oriented user study, this project was subject to several limitations that influenced the process, scope and interpretation of the results. These limitations primarily stem from project and methodological constraints.

Access and Development Constraints

One limitation concerned access to the system environment. While the physical machines were available through booking the company laboratory, a simulation of the system was initially considered the most practical option for frequent and flexible access. However, technical difficulties delayed access to the simulation environment

longer than expected. This affected early planning and reduced the time available for exploration and validation. Earlier access could have supported more extensive preparation by the research team and enabled a longer or more exploratory test design.

Another limitation concerns the timing of updated system directives. New requirements for the machine were introduced after the initial Lo-Fi testing had already been completed. While these directives were incorporated into the Hi-Fi prototype, conducting a full ideation phase at the same depth as the initial Lo-Fi exploration was not possible due to time constraints. Receiving finalized directives earlier would likely have enabled a more systematic exploration of alternative design solutions and reduced the amount of redesign work required later in the process.

Prototype Fidelity and Interactivity

A further limitation relates to the level of interactivity supported by the prototypes, particularly during the Hi-Fi evaluation. Although the Hi-Fi prototype was partially interactive, not all interface elements or system behaviours could be implemented. Several participants attempted to explore beyond the available interaction paths, such as accessing additional step statuses or modifying the product grid. Allowing this form of exploration could have provided deeper insights into user understanding and information needs. However, implementing full system logic and interaction behaviour in Figma would have required substantially more development time, additional views and complex interaction logic, which was not feasible within the scope of the thesis.

Closely related to this limitation is the fact that participants never operated the actual physical machine during testing. Instead, interactions were simulated through a paper-based setup or the digital prototype. While the paper cutout used during Hi-Fi testing supported participants' understanding of internal machine movements, it could not fully replicate the tactile, temporal, or situational aspects of operating the real machine. Direct interaction with the physical machine may have improved understanding of spatial mapping and process flow and could have influenced how the interface was perceived and evaluated.

Participant Selection and Representation

Participant selection also represents a limitation. Due to confidentiality constraints and the geographic distribution of actual machine operators, usability testing was conducted exclusively with company employees rather than operators who work with the machine on a daily basis. Although participants had varying levels of technical expertise and familiarity with the existing system, they did not fully match the profile of end-users performing regular operational tasks. Testing with experienced operators could have yielded more nuanced and practice-based feedback, particularly regarding workflow efficiency, error handling and long-term usability concerns. Their absence limits the extent to which the findings can be generalized to real-world operational contexts.

Testing Context and Evaluation Framing

Finally, the testing context and stated purpose of the evaluations may have influenced participant behaviour. Many participants had limited or no prior experience with usability testing, which may have resulted in initial hesitation or self-consciousness during the sessions. In addition, participants were informed that the Lo-Fi tests focused on gathering requirements, whereas the Hi-Fi tests aimed to validate a near-final design. This framing may have affected how critically participants evaluated each prototype, potentially contributing to more critical feedback in the Lo-Fi phase and more positive responses in the Hi-Fi evaluation, despite instructions to remain neutral and honest.

In summary, while these limitations constrain the scope and generalizability of the findings, they do not invalidate the results. Rather, they provide important context for interpreting the outcomes of the study.

6.6 Future Work

The proof-of-concept interface developed in this thesis provides a solid foundation for further refinement and implementation. Findings from the Hi-Fi testing sessions highlight certain areas for improvement, suggesting directions for future work. For instance, minor interface details could be enhanced to improve consistency and clarity. One example is how unit status is communicated during unload instructions. Although failed units are clearly presented through text, there is no equally clear visual indicator confirming when the process has been successfully completed.

Additionally, the results indicate a need for further guidance when alarms occur, as some users experienced uncertainty regarding how to proceed in such situations. Providing users with more actionable instructions could therefore enhance clarity and usability. Another potential improvement involves incorporating an animated turntable in the interface to represent the real-time behaviour of the turntable in-

side the machine. This could help users better understand the ongoing process and improve clarity.

Furthermore, this project was limited to exploring a subset of possible failures, errors, and alarms. Future work should therefore focus on examining all potential system states in order to enable a comprehensive understanding of what information needs to be presented in the interface and how it should be structured to support user decision-making.

Another area that was not extensively explored due to time constraints concerns the different types of user logins. Different end users have distinct permissions that determine which features and information are available to them. In this project, the interface was designed to include all available functionality, as it was considered easier to remove unnecessary elements than to add missing functionality. Future work should, however, focus on how the interface can be tailored to different user roles to ensure that each user group is presented with relevant features and information.

Finally, an important step toward a fully functional system is the technical implementation of the interface, which extends beyond the proof-of-concept design developed in this project. This includes translating the design into code, integrating it with back-end systems and conducting further iterative testing and evaluation to ensure correct system behaviour, effective support of user workflows and a high-quality user experience.

7 Conclusion

This master thesis explored how a user-centered design approach can support the redesign of industrial machine interfaces. The project focused on analysing an existing camera production system interface to identify usability issues, user needs, and operational requirements, which then guided the development of a future proof-of-concept machine interface. The project combined heuristic evaluation, usability testing, interviews, surveys, and iterative prototyping throughout both low-fidelity and high-fidelity design phases. These methods provided valuable qualitative and quantitative insights into how users experienced the interfaces and highlighted areas where usability issues affected workflow and interaction.

The pre-study revealed several usability problems within the existing system, including unclear terminology, inconsistent design elements, insufficient guidance, and an overload of technical information. Based on these findings, the redesigned prototype focused on improving navigation, workflow clarity, visual consistency, and error communication to better support users during operation.

The resulting high-fidelity prototype demonstrated clear improvements compared to the existing system and was perceived as more intuitive, structured, and easier to understand. The interface also supported users with varying levels of technical expertise, emphasizing the importance of designing for different user groups and experience levels. Overall, the results provide a strong foundation for the implementation of the future machine interface, while also highlighting the need for continued refinement of design details, expanded functionality, and further usability testing.

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A Appendix

This appendix presents enlarged versions of interface views as well as affinity diagrams, including extracted quotes and the resulting themes from different design phases.

A.1 Pre-study – Current Camera Production System Interface

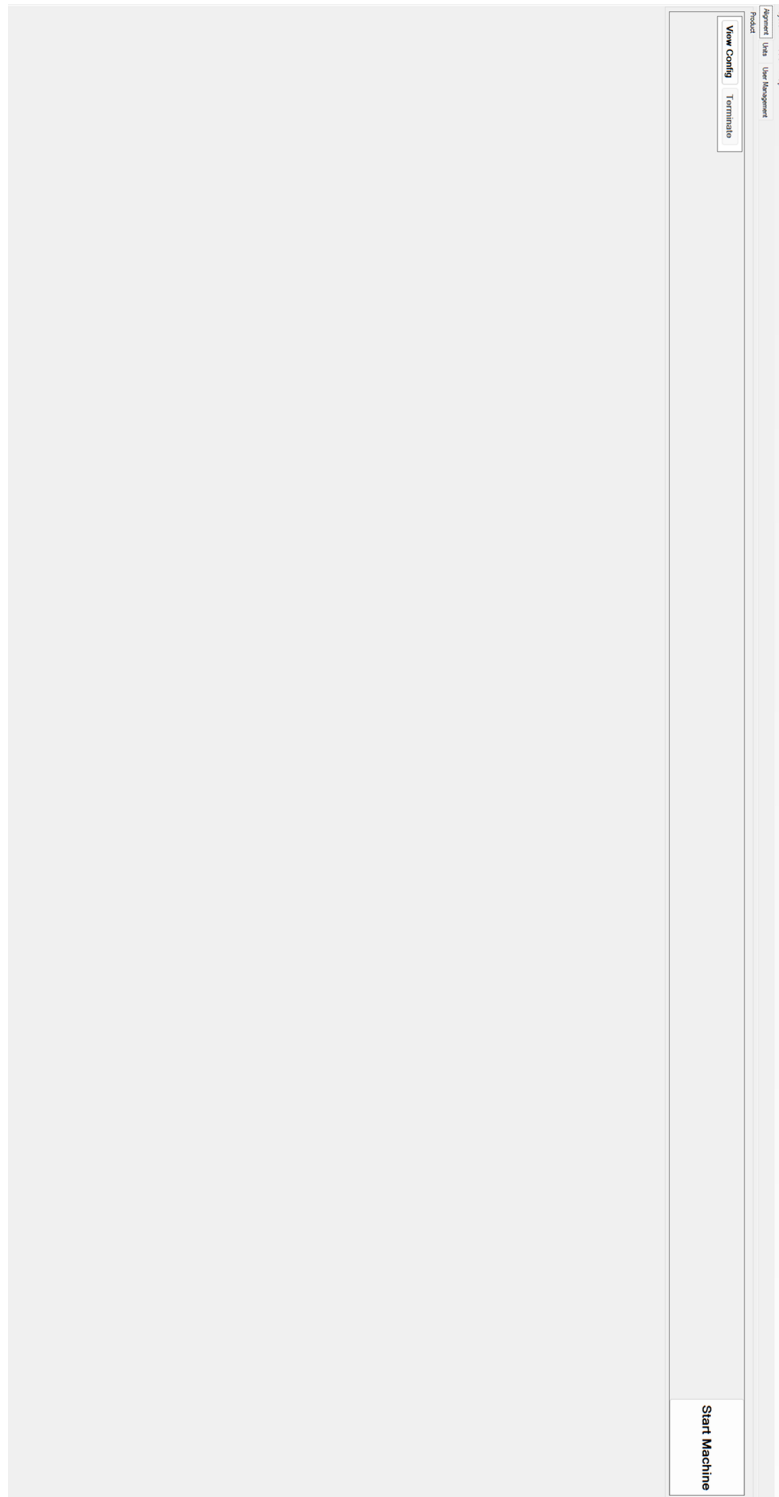


Figure A.1 Enlarged version: Start screen of the camera production system interface

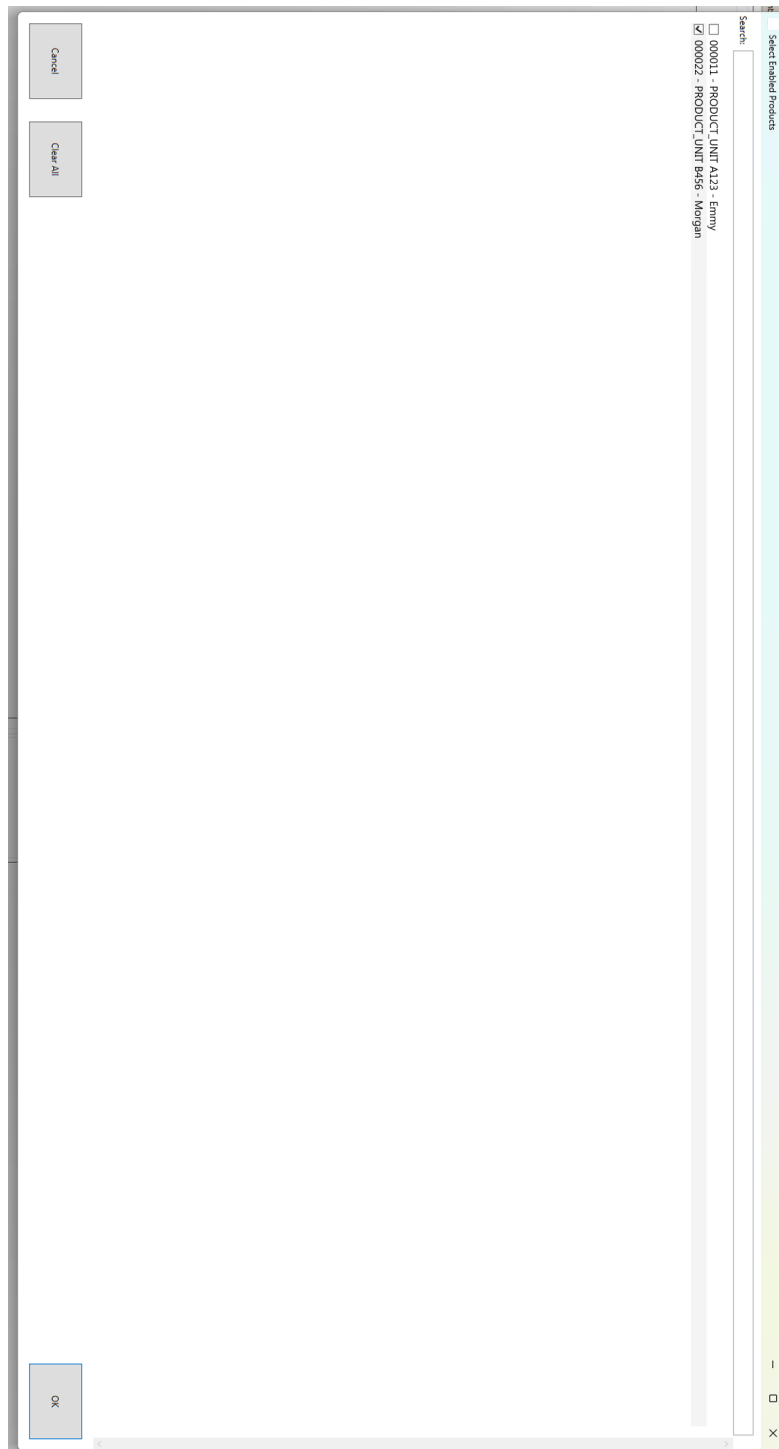


Figure A.2 Enlarged version: List of available products

File

Select Product

000011
A123

000022
B126

Order Identifier:

Order Subtype: 0 Production (Default) ▾

Cancel

Empty

PRODUCT UNIT A123

Product Module - 000011

Fixture color - black

Fixture part 1 - 8182937

Fixture part 2 - 1845971

Fixture holder

Fixture part 3 - 2070391

Next

Figure A.3 Enlarged version: Product Information Field

127

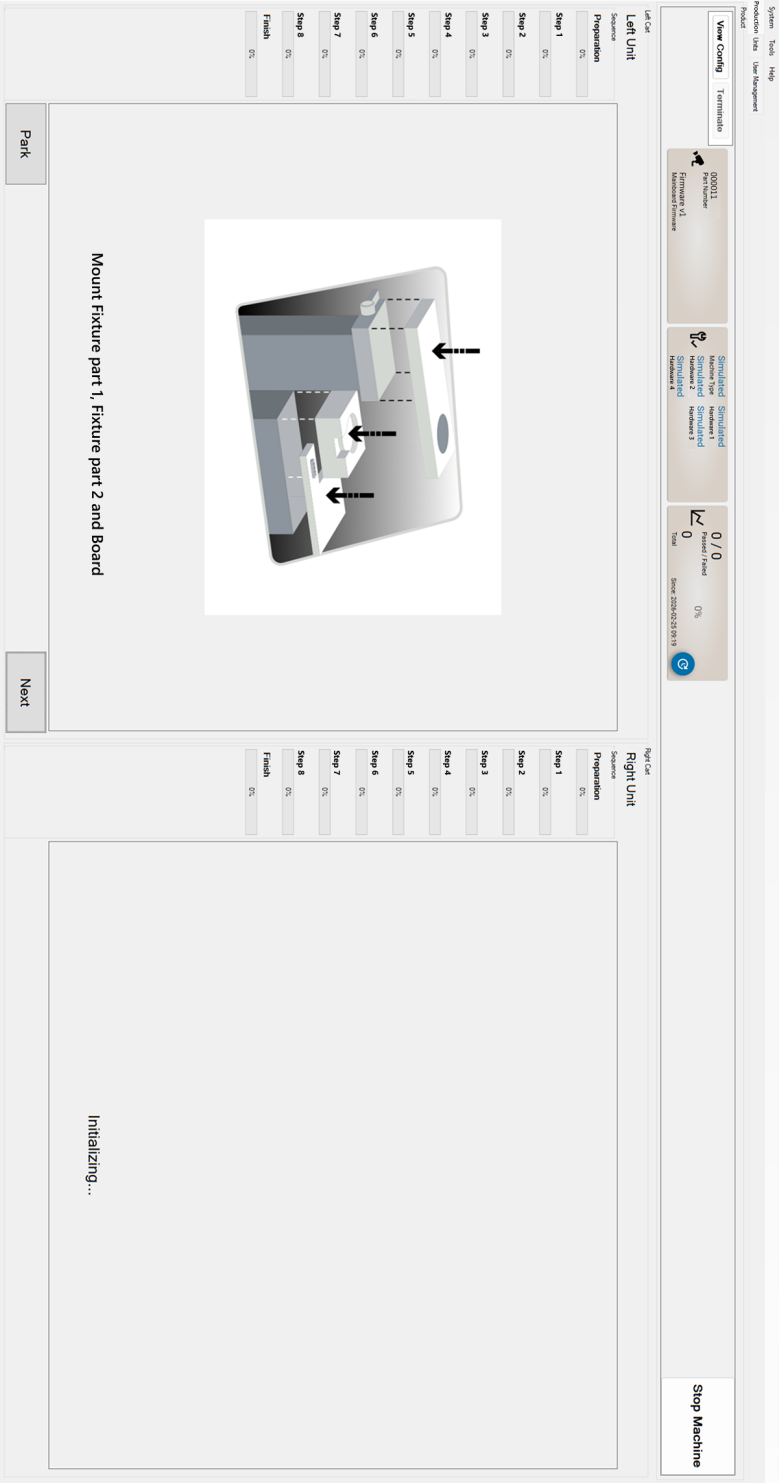


Figure A.4 Enlarged version: Mount unit instructions

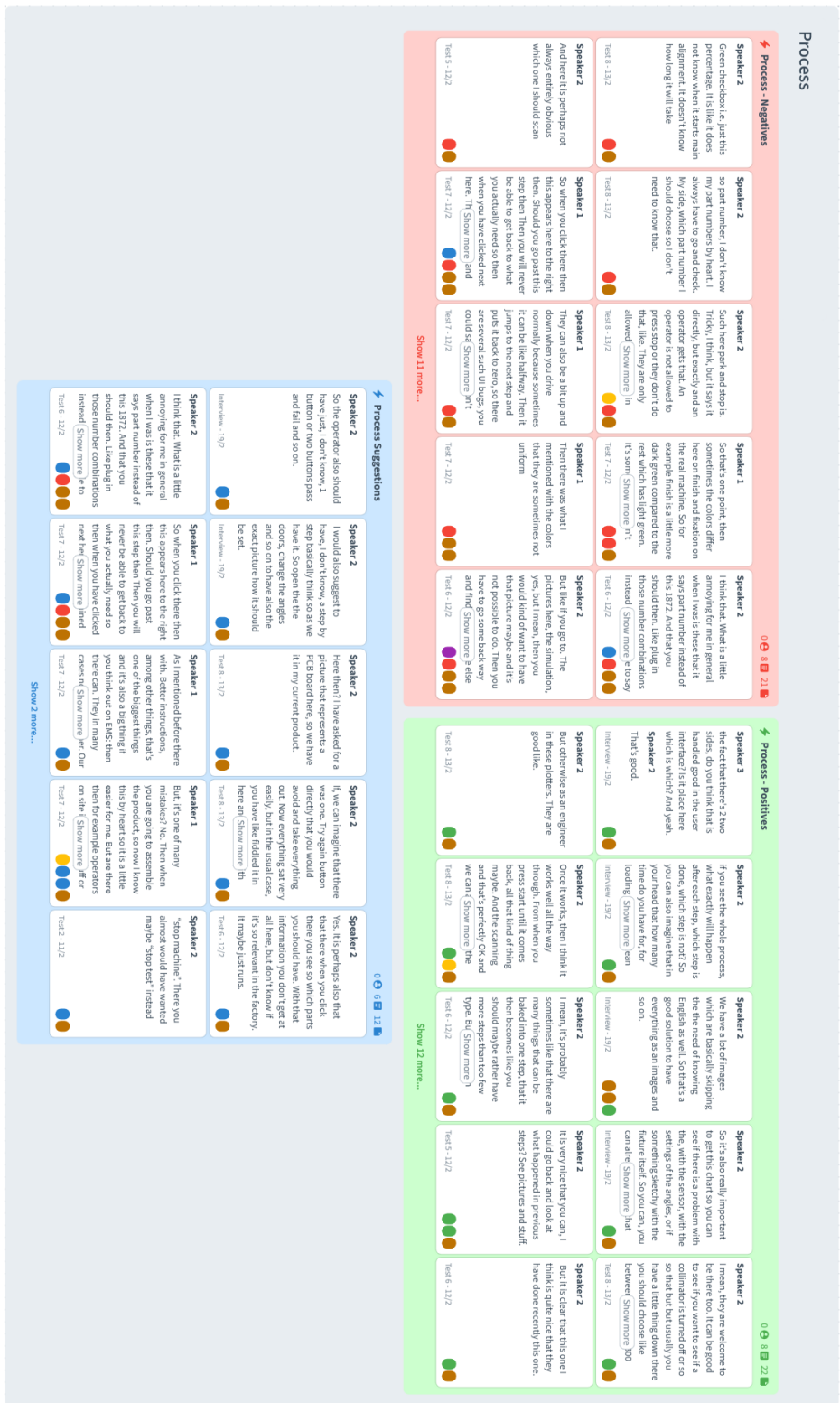


Figure A.5 Enlarged version: Quotes affinity diagram

A.2 Lo-Fi

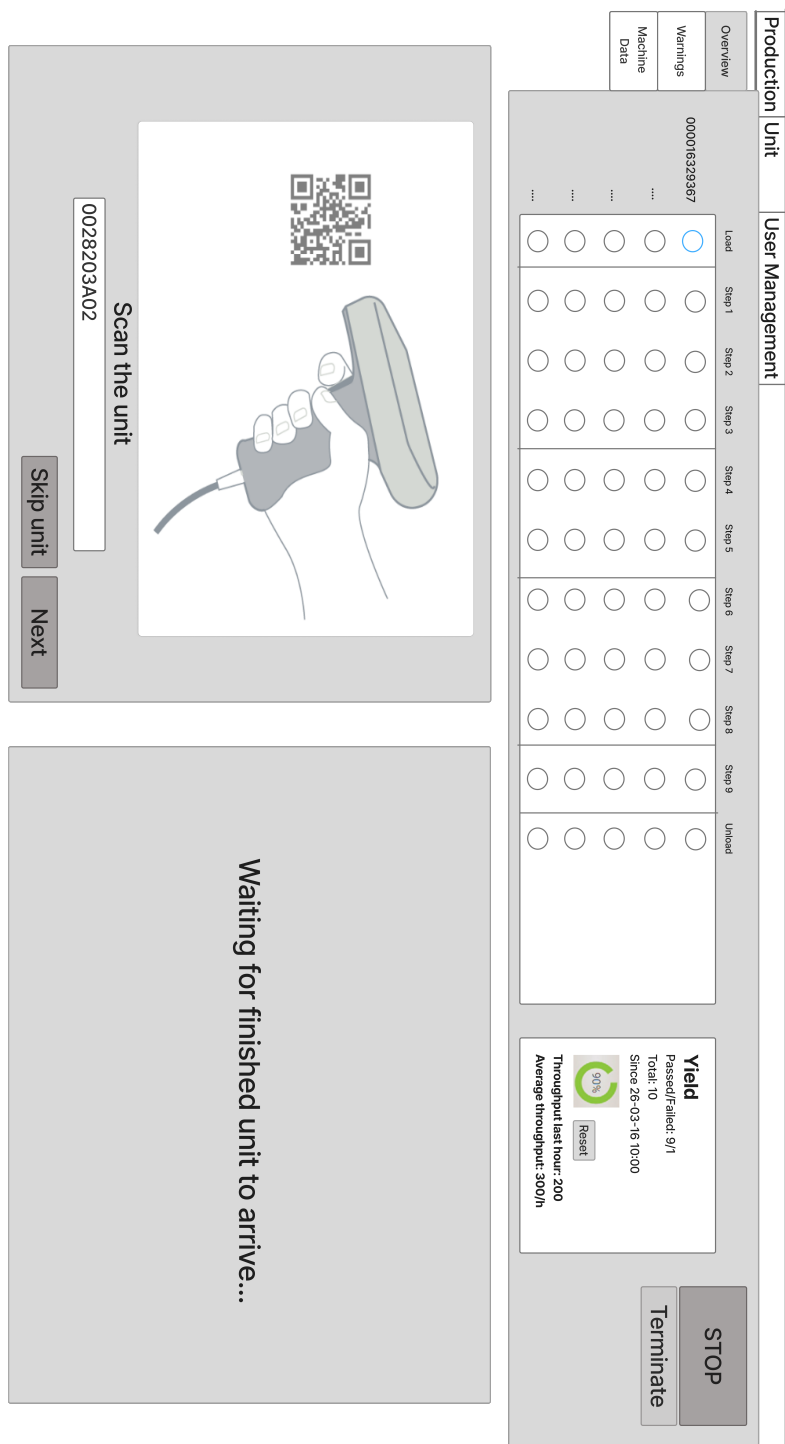


Figure A.7 Enlarged version: Updated layout of the process view

A.3 Hi-Fi

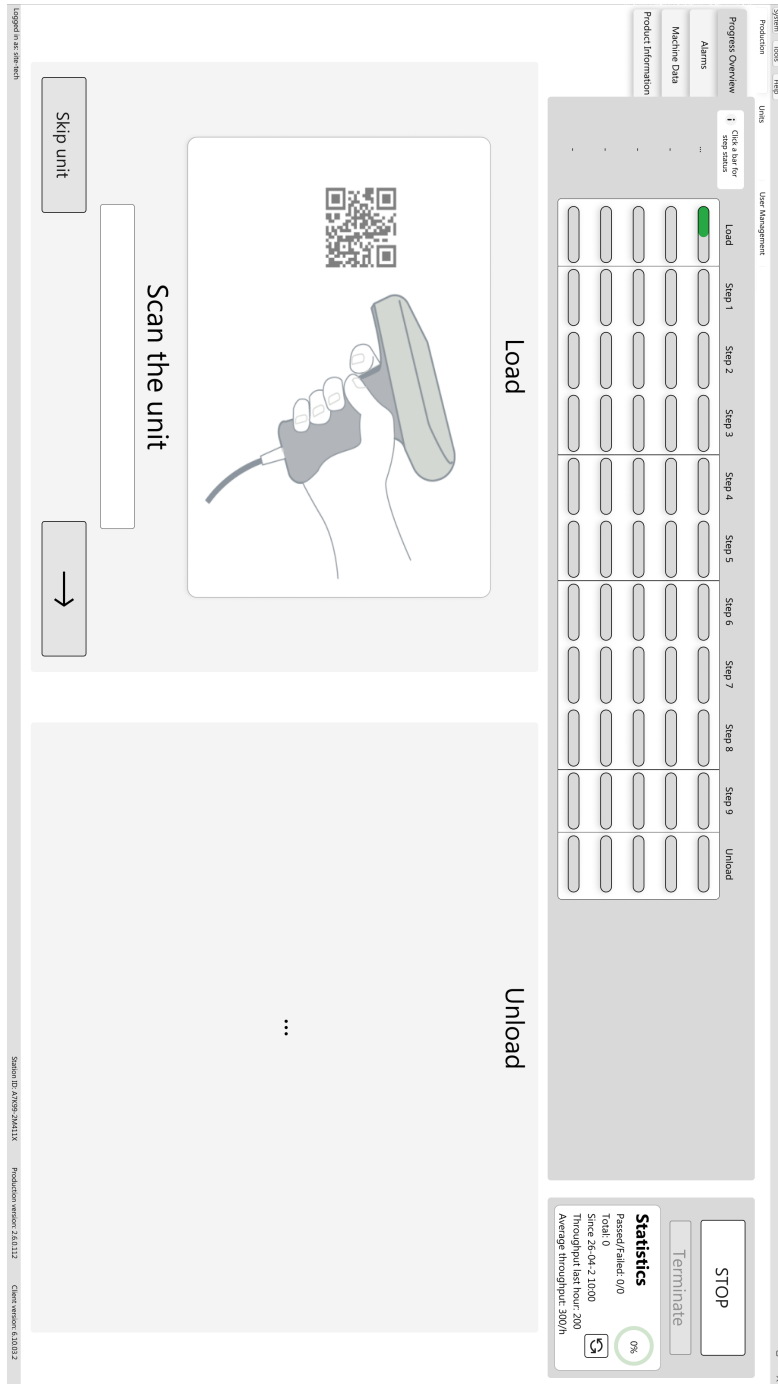


Figure A.8 Enlarged version: Scan unit instruction – Hi-Fi

Positives	Negatives	Suggestions
Easy fault identification	Unclear product confirmation	Progress Overview improvements
Appropriate level of information	Unclear terminology and naming	Failure pop-ups for clearer feedback
Relevant failure details	Excessive technical information	Progress bar improvements
Simple design	Unclear Progress Overview elements	Improvements to the main view
Clear mapping and intuitive symbols	Insufficient guidance on alarm resolution	Clear alarm handling instructions
Progress overview	Missing information in remove field	Changes to terminology
Accessible product and machine information	Too small elements	
	Inconsistent design	
	STOP button distracts in Alarms	

Figure A.9 Enlarged version: Hi-Fi themes