Tampere University

Muhammad Ahmed

DESIGNING AND VALIDATING SAFETY COMPONENTS IN VALMET'S AUTOMATION SYSTEM

A study of Valmet’s safety components

Faculty of Information Technology and Communication Sciences
M. Sc. Thesis
October 2024

ABSTRACT

Muhammad Ahmed: Designing and validating safety components in Valmet's automation system
M.Sc. Thesis
Tampere University
Master's Degree Programme in Computing Science
October 2024

Safety components and protocols are a crucial part of any automation process. The goal of this thesis is to design and validate safety components for Valmet's automation system. This research explores three research questions: the flexibility of current guidelines to support new components, find ways to improve the effectiveness of the safety components' design, and to answer if the new designs satisfy the user needs by providing clear communication about the emergency. The study was conducted in several phases. The first step was to understand the requirements of the safety components, and that was achieved by doing three semi-structured interviews and a focus group with industry experts. The gathered insights helped drive the design process to create the safety components. Ten semi-structured interviews, and surveys were taken from the on-field operators that helped validate the concepts and designs for the safety components. The study revealed that 80% of the operators could differentiate between the normal and the safety components. It can be concluded that the designs are effective in communicating the emergency just by their visuals. The study also validates the use of black and white stripes to show the emergency related to the safety components as it uses the already existing mental model from the real-life danger/warning zones. Moreover, the study also proves the flexibility of current guidelines available for normal components.

Keywords
Safety components, automation, Valmet, safety guidelines, design validation, Safety devices, automation industry.

USE OF AI IN THESIS

I have utilised AI tools in my thesis:

☐ No

☒ Yes

The AI tools utilised in my thesis and their purposes are described below:

Names and versions of AI tools: Grammarly

Purpose of using AI tools: Grammarly was used to enhance the writing quality of the thesis. Grammarly's grammar correction was used to see any errors in the grammar. Moreover, rewrite feature was also used from occasionally to enhance the readability of certain sentences.

PREFACE

I would like to express my deepest gratitude to everyone who has supported and guided me through this thesis. Without their invaluable assistance, this work would not have been possible.

I would like to extend my sincere gratitude to Mira Tuominen, my manager at Valmet, for her support and guidance during this thesis. Her belief in my abilities and insightful feedback were crucial to the completion of this thesis. I am also thankful to my supervisor, Päivi Majaranta, for her invaluable advice and constructive feedback, which greatly enriched my work and kept me motivated.

A special thanks to Nina Flink, our UX lead, for her mentorship and patience throughout this process, which significantly improved the quality of the thesis. I would also like to thank Jukka Järvelä for his invaluable assistance in conducting the interviews in Finnish and his support in refining the survey.

Finally, I am deeply grateful to my family. To my mother, for her endless love and encouragement, and to my late father, whose wisdom and guidance continue to inspire me every day.

Tampere, 16 October 2024

Muhammad Ahmed

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

The fast-paced industry of automation calls for robust safety systems that can preserve human life in the emergency. Considering the ever-growing evolution of automated machinery, the human safety and well-being within the production and manufacturing zones remains a constant challenge. As the automation industry flourishes and strives for more efficiency and productivity, it is important that the focus remains on the safety of the workers. Although, automation industry has grown to the point where human interaction with the machinery itself has reduced significantly, it is important to monitor the system and its safety. User experience (UX) designers are responsible to make this process intuitive and rapid. A good user experience can make a huge difference when it comes to how these emergencies are perceived by the operators. Usually in emergency situations, it is important to communicate the situation as quickly and effectively as possible, which is why one glance should be enough for the operator to understand at least the presence of an emergency. A literature review by Campilho & Silva (2023) shows the importance of involving operators in the design process to understand the end-user perspective. They also highlight the importance of using unique and descriptive symbols to reduce the cognitive load on operators. Valmet is one of the leading organisations in the automation industry, dedicated to providing the innovative solutions that promise efficiency and safety for its operators. A research lead by a reputable organisation can have a strong impact in the industry and provides a better understanding regarding the complex topics like safety and prevention.

The goal of this thesis is to understand the existing guidelines for the Valmet's normal components, and design safety components using said guidelines. The purpose is to understand whether the existing guidelines support the more complicated components that might require more functionality than normal components. However, it is crucial to understand that we should not cut any corners, or compromise when it comes to designing safety components. The ability of these components to convey emergency situations in a meaningful way is of the upmost importance. Therefore, the thesis also focuses on expanding the existing guidelines to support safety components, if proven to be otherwise. This thesis seeks to address three research questions:

1. To what extent do existing design guidelines for components align with safety components?
2. How can the user experience of safety components can be improved to enhance their effectiveness in communicating emergency situations and ensuring swift operator responses.
3. To evaluate whether new designs satisfy the requirements and communicate the emergencies efficiently.

The first question aims to understand whether the existing component guidelines are flexible enough to support safety components or not. Do these guidelines meet the needs of users in real-world automation scenarios? The aim of the second questions is to understand how to design safety components that are reliable, efficient, and communicate the emergency clearly and intuitively. To answer these questions, a comprehensive research approach was employed, which involved interviews and focus groups with industry experts, product owners, and operators to understand the requirements, design the components, and evaluate them with end-users. The aim of this research is to contribute not only to the enrichment of Valmet’s products but also to contribute to the safety and UX design within the automation industry.

The structure of this document is as follows. Chapter 2 outlines the background information, such as what components are in Valmet's automation systems, what guidelines are currently being used, previous research done by Valmet on safety HMIs, and international standards (ISOs) that shape the guidelines for the overall system's user interface (UI). Chapter 3 discusses the research methodologies used during this research. It also explains using the human-centred design (HCD) approach, pre-study methodologies, and the design and validation process. Chapters 4, 5, and 6 break down the research methodologies and provide further details regarding methods used during different research stages. Chapter 4 discusses the pre-study methodologies used during the pre-study phase. The chapter also includes the results of the pre-study part of the research. Chapter 5 entails the design process for the safety components. This chapter explains how and why the design decisions were made for designing the safety components. Chapter 6 contains validation methods used for validating the safety components as well as the raw results. Chapter 7 discusses the results in detail and interprets the results to make sense of the findings. Chapter 8 discusses the implications of the results and offers a critical analysis of the findings. Chapter 9 concludes the research and summarises the main contributions of the thesis and the overall impact of the study.

2 BACKGROUND

Designing for the automation industry and large production sites usually means following standards and guidelines to ensure industry standards and quality control. The same applies to designing ‘process components’ for automation UI. However, companies might also have additional guidelines for designing and developing components for their projects. In Valmet's case, process components, faceplates, pages, and other UI components have their own set of guidelines that user experience (UX) designers must follow to ensure consistency between projects. This thesis's background section discusses the standards and guidelines that shaped the UX of Valmet's automation and, ultimately, safety components. The background section will also discuss what "components" are in Valmet UI so, readers can better understand the terminology.

Although abundant literature is available when it comes to design guidelines for critical systems, there is a notable lack of research focused on designing and validating safety components. Most literature tends to focus on the broader safety standards or design standards, but the lack of research when it comes to specific design principles for safety components and their validation is apparent. One reason for the lack of this research is the confidentiality nature of these systems. Most companies do not want their research to be public before their systems are. Additionally, studies that validate the effectiveness of these components, particularly from a user-experience perspective, are relatively scarce. This thesis addresses this gap by providing a structured approach to the design and validation of safety components, incorporating real-world feedback from operators.

2.1 Human machine interface (HMI) design

While establishing the guidelines for components, guidelines for human-machine interface (HMI) were considered. Human-machine interfaces, also known as HMIs, are what bridge a connection between a machine and a human and allows humans to operate the machine (Stouffer, 2019). HMIs can have multiple forms depending on the type of machine and controls it offers. For the scope of this thesis, the HMIs are referred to as digital machine interfaces used in control rooms to monitor and control the production environment. HMIs for industrial applications should follow specific guidelines to provide smooth and efficient interaction between a human and a machine. Although there are many sources available for such guidelines, it is important to understand their scope and how much of those guidelines can be followed in a particular system. Valmet already has its own set of comprehensive guidelines that facilitates the design process of its interfaces.

A journal from Flink et al. (2024), gathers HMI design standards and guidelines from multiples sources; including, books and ISO standards to derive the designs of Valmet's interfaces and define internal guidelines for future designs. These guidelines extend to the components that are used in Valmet's system today. Hollifield et al. (2008), discusses some characteristics that a well design HMI should have. According to him, high performing displays should use grey or neutral backgrounds, shouldn't be unnecessary animations, should have limited use of colour, should have a layout that utilises operator's mental models, should have a hierarchical structure. These characteristics are also mentioned by Flink et al. (2024) along with some extended characteristics that should be present in an HMI if an abnormal arises. One of these characteristics also focuses on using minimal colour in the UI during normal production conditions so when an emergency situation arises, the coloured notification will divert operator's attention to the alert (Vincente et al., 1999 as cited in Flink et al., 2024). These characteristics and guidelines serve as the basics to create interfaces and components for industrial application. The component guidelines (section 2.3) will also reflect these characteristics that are described in the journal by Flink et al. (2024)

2.2 Components in Valmet's automation UI

Valmet's automation UI consists of various elements, including pages, faceplates, process components, and Cetra (*Control Room Solutions—Valmet DNAe User Interface*, 2024). Process UI components generally consist of symbols, numerical values and text (often abbreviations) (Lehtikunnas, 2022). These components can range from a simple motor to more complicated composite components that combine multiple components to act as one. For example, a motor component in its basic form can be a single component; however, when required, additional components can be added to improve the functionality (see figure 1). Those additional components can be a related value box to show the speed of the motor or perhaps an indication of the operating mode of the motor.

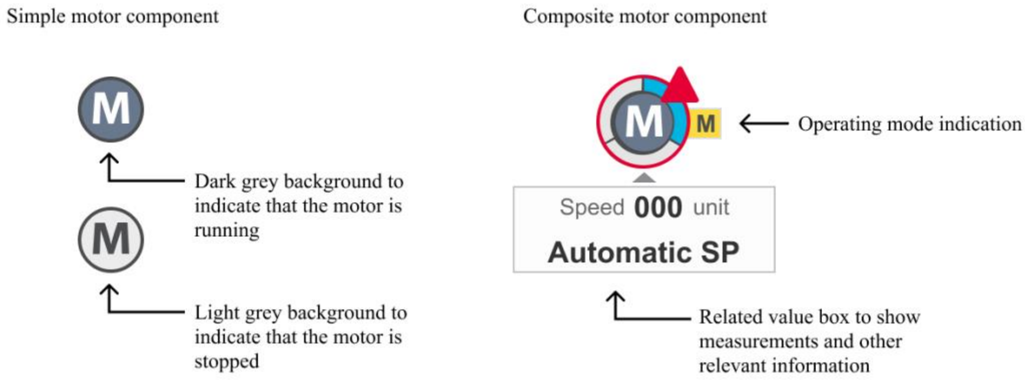

***Figure 1** Process component example*

The process components can vary greatly depending on their nature and functionality. For example, more complicated composite components can be a trend tool, PID component, or even a faceplate. This expansive group of components means the guidelines should be flexible enough to support all the components but not too flexible to become vague. Designing safety components while conforming to the existing guidelines should not be an issue. However, there should be no compromise since safety components must communicate the emergencies clearly, so the operators know what actions to take when an emergency arises.

The components are usually a part of a page. In other words, a page consists of multiple different components related to the machine section that a certain page belongs to. For example, a page can consist of multiple motor components, data visualising components (e.g., bars, related value boxes, trends, etc.). In the following example of a page from Valmet's DNA UI, multiple component types can be seen. For example, input fields, dropdowns, process components, and diagrams to represent certain machine parts. The components work together to provide a complete and logical experience to operate and observe the production. Figure 2 and figure 3 provide two examples of such pages in Valmet's automation system.

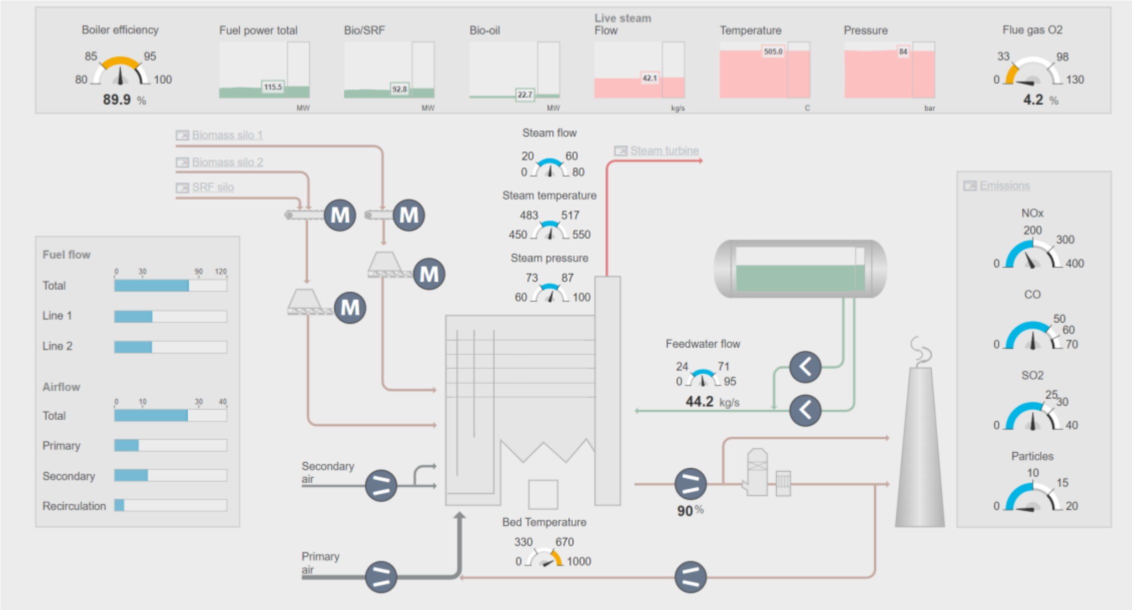

Figure 2 *Example 1 of a page in Valmet's system*

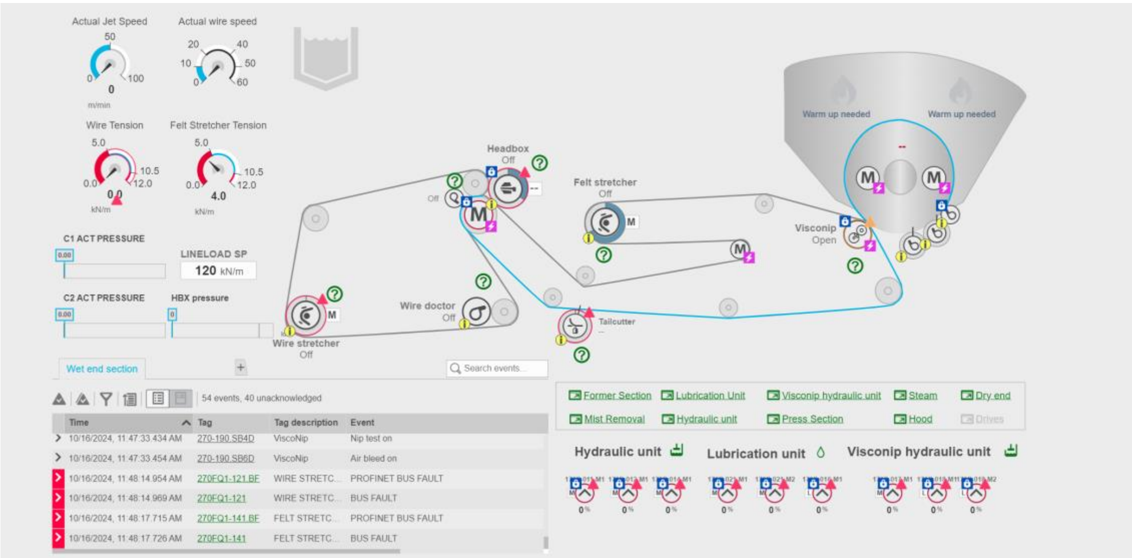

Figure 3 *Example 2 of a page in Valmet's system*

2.3 Component design guidelines

Like many organisations, Valmet has a set of design guidelines that designers must follow to create new components, faceplates and pages. These guidelines ensure the design of a consistent, informative, and an easy to navigate and use user interface, that ultimately contributes to enhancing efficiency and safety in industrial environments. To design safety components, it was crucial to comprehend the current guidelines and understand them completely. A deep dive into these guidelines was necessary to understand their flexibility and limitations. While designing the safety components, the already existing component guidelines were used; hence, it is important to lay them out in the document, so it is easier for the readers to understand the choices made while designing the safety components. Following are the basic design principles used to design normal components of any kind.

2.3.1 Principle 1: Using title and subtitle

According to the Valmet's internal guidelines, the first principle highlights the importance of using titles and subtitles to identify the component and display additional information regarding its state (see figure 4) (Uusitalo, 2022). A page can consist of many similar kinds of components, for example, a page can have multiple motor components, so it is important that an operator know which motor they are going to operate, or which motor is alarming at the moment. Hence, providing a descriptive title and a subtitle is important to make the identification process easier for the end-users. The principle of using clear titles and subtitles in HMI design aligns closely with the usability guidelines outlined in ISO 9241-11:2018, *Ergonomics of Human-System Interaction – Part 11: Usability: Definitions and Concepts*. These standard highlights that the design of interactive systems should enhance efficiency, effectiveness, and satisfaction for the end user, particularly in complex environments like automation systems. By ensuring that critical components are identifiable, and their states are easily interpretable, the use of titles and subtitles supports usability by reducing cognitive load and the likelihood of errors. The naming convention can differ from project to project; however, the purpose of the title and subtitle stays the same. An example of title and subtitle could be a "hold-to-run" component with a title "Hold-to-run: Left" and "Hold-to-run: Right". Here, both components are "hold-to-run", however, they can be differentiated by their positions in the machine, which are "left" and "right". The subtitle can be used to provide additional information about the component, depending on the need. For example, subtitle can be used to further identify the component in complex machines or to display the state information. In the case of state information, the subtitle should display the state of the component using straightforward and clear text. In the case of "hold-to-run" component, the states can be "running", "Idle", "crawling", and "reverse running". Operators can easily see the current state of the component, without having to do any additional operations, e.g., opening the faceplate.

Figure 4: *Principle 1 example*

In the figure 4, the text in bold is the main title of the component that is used to identify the component, and the second text is a subtitle used to either further identify the component or to show the current state.

2.3.2 Principle 2: Using descriptive symbols

The second principle highlights the importance of using descriptive symbols/icons for the components (see figure 5) (Uusitalo, 2022). In Valmet's UI, symbols are used as a visual representation of a component and its state. The principle of using descriptive symbols aligns closely with the guidelines provided in the article *"Experiences in More Effective HMI Concepts at Pulp and Paper Mills."* The study emphasises that effective HMIs should allow operators to instantly recognise system states and understand contextual information without unnecessary cognitive load. For instance, it highlights the importance of designing visual elements to present process information in meaningful ways, such as embedding trends or using minimal but impactful animations for abnormal situations (Hollifield et al., 2008). These symbols/icons are a way for the operator to recognise and understand the state of the component in one glance. For example, a motor component can have different symbols that can mean different things, e.g., running, running forward, running reverse, crawling, crawling reverse, etc. All these states have their own representation withing the symbol with a common motor symbol. The dynamic nature of these symbols allows them to change according to the situation; hence, removing any ambiguity while keeping operators up to date. Figure 5 elaborates on this example to show how component symbols can be used to show different states.

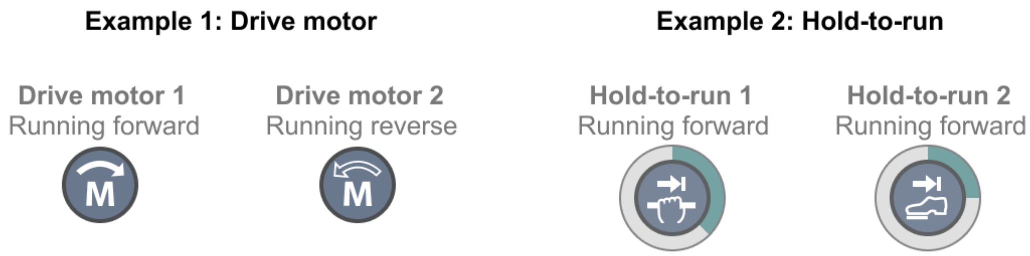

Figure 5: *Principle 2 example*

In the figure 5, “example 1” shows the drive motor component in two running states. When the motor is running forward, it is clearly indicated using the forward arrow. Similarly, when the motor is running in reverse, the backward arrow is shown to indicate that. Moreover, the hollow arrow represents the unnatural running direction. In the second example, the hold-to-run component is shown. However, there can be different kinds of hold-to-run switches, i.e., hand-operated and foot-operated. To differentiate between the two, different symbols are used, even though, the component itself and its functionality is the same.

2.3.3 Principle 3: Using filled/not filled states

The third principle discusses about the use of filled and non-filled component backgrounds to indicate the state of the component. Unlike principle 2, the filled and non-filled states can only show “running” and “stopped” states. The terms “running” and “stopped” are not true for all components, some components might have different terms to indicate these states. For example, some component might have “enabled” and “disabled” states instead. A filled component background indicates the “running”, “enabled”, or “active” state, meanwhile, a non-filled background indicates the “disabled, “inactive”, or “stopped” state. For example, a running motor has a filled, dark grey background while a stopped motor has unfilled, light grey background. This visual distinction can help operators recognise the component’s state in one glace. The figure 6 demonstrates this visually for better understanding.

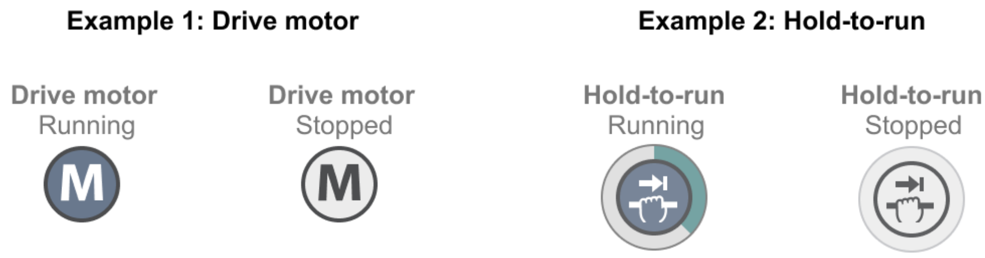

Figure 6: *Principle 3 example*

2.3.4 Principle 4: Using blinking animation

The fourth principle emphasises on using the blinking animation to indicate any transitional states (Uusitalo, 2022). The use of these blinking animations is situational and depends on how long these transitional states last. For example, when a drive motor is turned on, it takes some time to reach its full speed. While the motor is picking up the speed, the blinking animation should be used to indicate that the motor is not running at its intended state. The same applies for any component that takes more than a few seconds to change it state. The blinking animation can indicate various states including starting, stopping, opening, closing, loading, shutting down, or changing the motor's directions. The main purpose of this blinking animation is to indicate the important transitioning states that might be useful for the operator to know right away. These states also help keep the visibility of the production clearer.

2.3.5 Principle 5: Using Status Indicators

The fifth principle focuses on using common indicators to indicate different conditions such as alarms, signal faults, forced controls, actuator faults, safety interlocks, cations, simulations, and operating locks (Uusitalo, 2022). The principle of using status indicators for abnormal situations aligns closely with best practices in Human-Machine Interface (HMI) design (Flink, 2024). The article by Flink et al. (2024) emphasises the critical role of visual indicators in maintaining situation awareness, especially during non-standard or emergency situations. Indicating these conditions/states is crucial since these indications are shown usually during abnormal situations. Each indicator has its own position on the component boarder depending on its priority. Since these indicators are the same across all the projects, they are easy to recognise and always mean the same thing. Depending on the situation, some indicators have variables to show different priorities. For example, an alarm indication can have varying colours depending on the alarm's priority. These indications are an important visual element in Valmet's UI to rapidly indicate any unusual situations and communicate the urgency in a fast and unambiguous manner. The figure 7 illustrates all the status indicators available in Valmet's UI and how they look like when actuated.

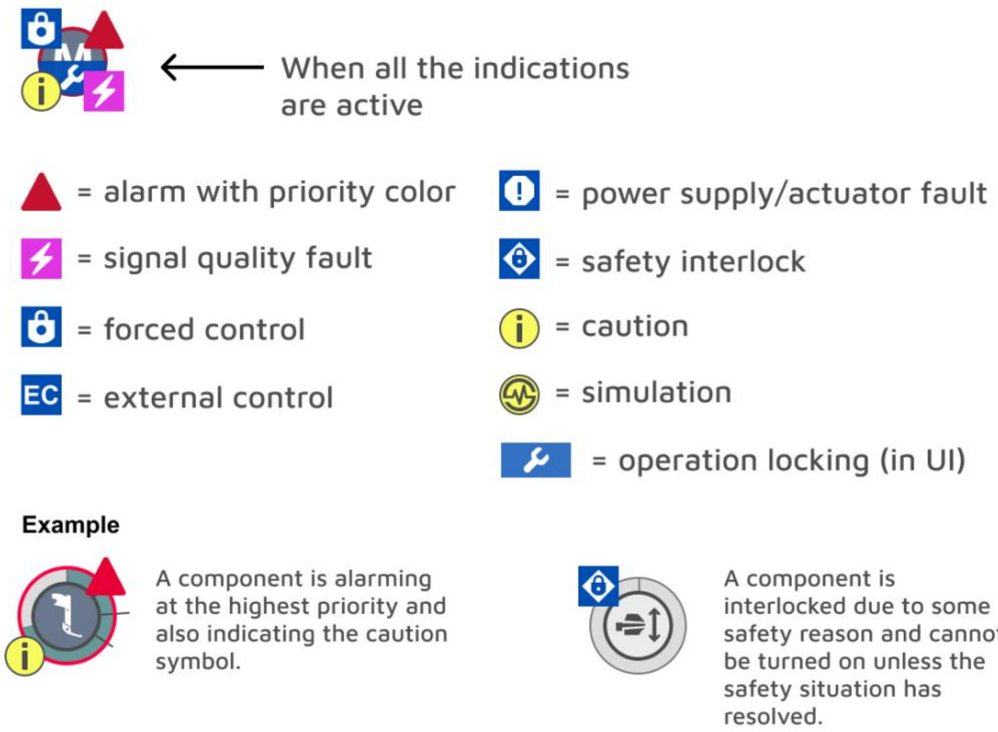

Figure 7: *Principle 5 example*

2.3.6 Principle 6: Using mode boxes

The sixth principle highlights the importance of using mode boxes to indicate the active operating mode of the component (Uusitalo, 2022). These operating modes can be automatic, local, manual, and remote. However, some components might have an operating mode that is linked to some other "parent" component, which is represented by a link icon. In this case, maximum two mode boxes can be used, one to indicate the link, and the other to indicate the current operating mode. The components can be operable and inoperable, which is indicated by the greyed-out background of the mode boxes. In some cases, an operating mode can be forced; for example, an operating mode can be forced to automatic, manual, and local. Moreover, abnormal modes, meaning the modes that are not preferred, will be displayed with a yellow background. This principle is visualised in figure 8.

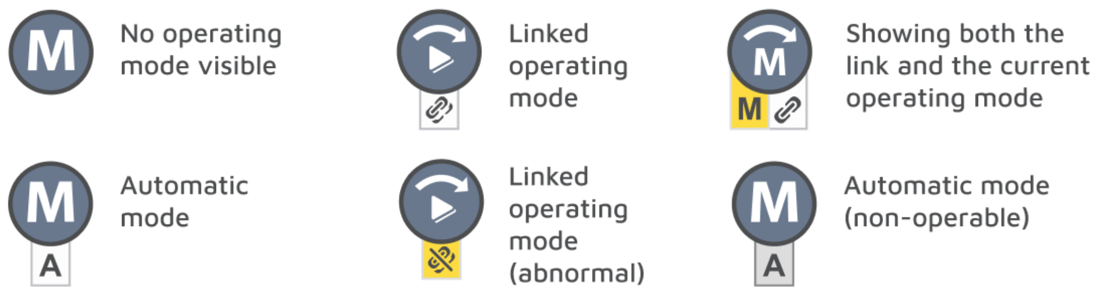

Figure 8. *Principle 5 example*

2.3.7 Principle 7: Using component frame

Using the component frame to provide additional information about the component's state is yet another way to visualise important information without having to do any additional operations i.e., opening the faceplate (Uusitalo, 2022). The principle of utilising component frames to convey additional information aligns with established Human-Machine Interface (HMI) design practices. A study on soft human–machine interfaces emphasize the importance of dynamic visual elements that adapt to real-time data, improving user interaction and system monitoring (Dong, 2018). This approach enhances operator awareness and efficiency by presenting critical data directly within the interface. The component's outer frame can be used to display a variety of information; for example, setpoints, main measurement (e.g., speed of a motor, weight, and angle). Moreover, component frames can also display the progress of steps that a component has to go through in a sequence, percentage of completion, and other useful information that an operator might need. Maximum two outer rings can exist to indicate two different values. This principle is quite flexible and can be used to indicate emergency situations by introducing new colours or mechanics to the component. In figure 9, uses of different kinds of component frames can be seen.

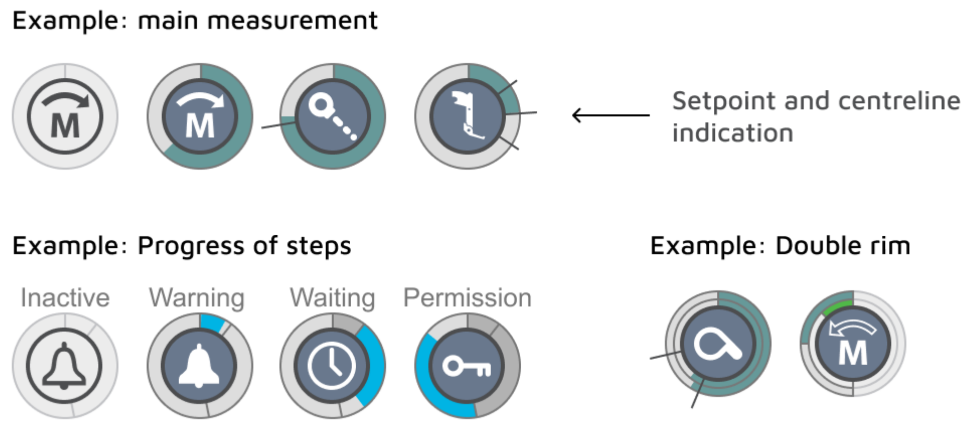

Figure 9: *Principle 7 example*

2.3.8 Principle 8: Using related value boxes

The eighth principle by Uusitalo (2022) allows for the use of related value boxes to display values and information related to the component. These related value boxes can be considered a component as well. The related value boxes are used alongside the main component to show related information such as measurements, operating modes, and other textual information. This information can also include units alongside the prefixes to show meaningful data that can be interpreted by the operators easily and clearly. The related value boxes can also include symbols and icons to indicate certain values. Doing so reduces the need to use the text which can often take unnecessary space. Figure 10 shows the use of related value boxes with main components.

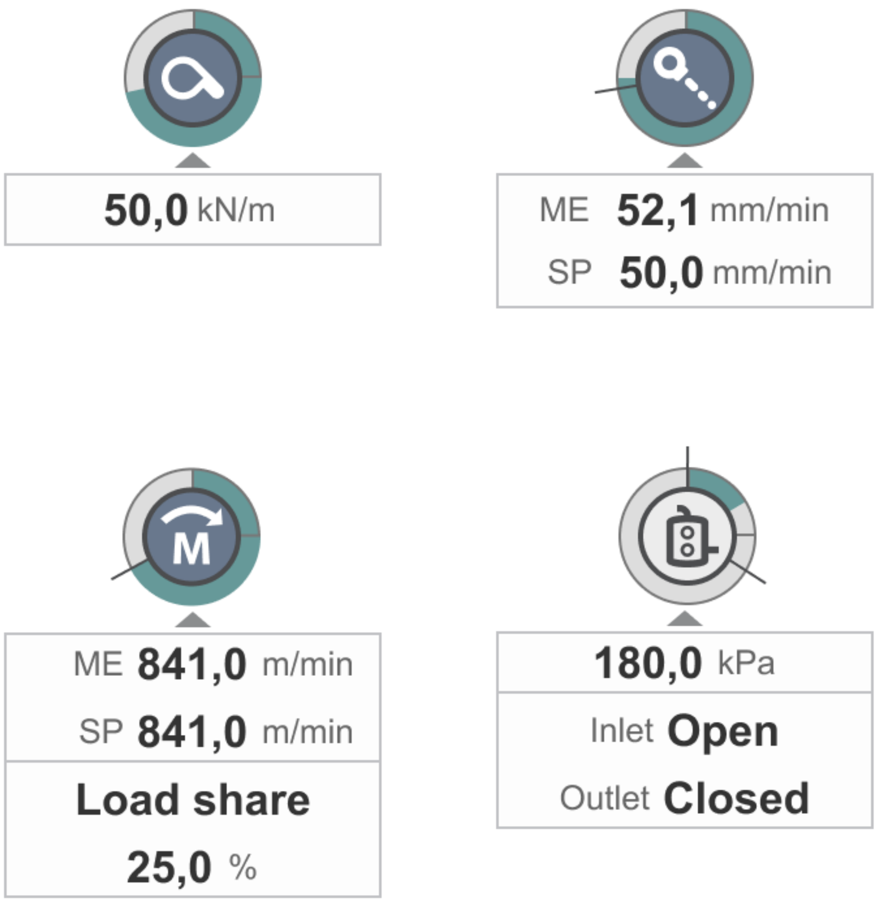

Figure 10: *Principle 8 example*

The component guidelines were designed keeping the usability heuristics in mind (Nelsen 1994). These guidelines and principles are responsible for the consistent component designs across all the projects. Moreover, they make sure that designers have a baseline for designing new components and keeping them in line with previous components and Valmet's quality design. The consistent visuals and patterns make it easier and faster for operators to recognise components and situations rapidly. While designing safety components, same guidelines were used to keep the consistent design.

2.4 Safety components

Safety components in industrial automation settings are devices that are used to protect operators from the risky situations that might occur during the automation process (*Machinary Safety of Safety Components | OMRON Industrial Automation*, 2024).

Human error and technical defects are inevitable and can cause accidents on production sites. It is crucial to understand, analyse, and predict the possibility of such errors and try to prevent them before they happen. Safety components are used to prevent such errors and often times can be the last line of defence between a life and death situations. Safety components have varied priority levels, some safety components are used to prevent accidents, while other can be just to indicate the danger or hazard. Figure 11 shows and example of a safety component.

Figure 11: *Safety gate component*

International organisation of standards (ISO) has various standards that must be followed in order to design for these safety components. These standards not only ensure the reliability of the system, but also provide a baseline for designing the components. A deep dive into these standards reveals that the underlying principles used to create these standards are based on UX heuristics and principles. For example, "ISO 13849-1: 2015 – Safety of machinery – principles for design" covers design and validation, which defines principles such as clear design, colour, placement, visibility, and other UX design principles that are already used in Valmet's normal component guidelines. Moreover, Valmet's components, faceplates, and pages are designed in consideration with relevant ISO standards. Following are some of the ISO standards that are relevant to the visual aspects of the safety components and are used in their creation as well.

2.4.1 ISO standards relevant to safety components

ISO standards are internationally recognised standards and guidelines that ensure the quality of products and services across numerous industries. Moreover, these guidelines also provide a baseline for many design processes for automation industry. When it comes to safety components, ISO standards provide guidelines regarding alarm systems, visual representation of alarms, notifications, design processes and much more. Following are some of the relevant ISO standards that were identified and used during the safety component's design process.

2.4.1.1 ISO 9241-210:2019 - Ergonomics of Human-System Interaction - Part 210: Human-Centred Design for Interactive Systems

This ISO standard provides guidelines regarding the design process that should be used while design for safety components. Though, this ISO standard does not specifically talk about safety components, it is a general standard for human-system interaction. Since, safety components in Valmet's UI systems are part of a human-system interaction, this ISO standard becomes relevant. ISO 9241-210 puts an emphasis on using human-centred design for interactive systems and use usability principles and iterative design process to design interactive systems. Valmet already practices these guidelines; hence, while designing and validating safety components, ISO 9241-210 was taken into the consideration.

2.4.1.2 ISO 11064-1:2000 - Ergonomic Design of Control Centres - Part 1: Principles for the Design of Control Centres

This standard provides guidelines regarding the ergonomic principles for designing control centres. These guidelines provide a baseline for designing UIs for the control centres which also include the placement and visual aspects of safety components. These guidelines also touch upon the visual arrangement of safety components for better visibility and readability. It is crucial to understand these standards in order to provide the quick reach and accessibility to these components in case of emergencies. Moreover, these guidelines also provide information regarding the physical ergonomics of the control centres. For example, use of monitors, equipment, and size of the screens. While designing for the control centres, these standards were taken into consideration.

2.4.1.3 ISO 13855:2010 - Safety of Machinery - Positioning of Safeguards with Respect to the Approach Speeds of Parts of the Human Body

Although this standard mostly describes the physical aspects of safety components, it is important to understand those in order to design for the UIs as well. This standard speaks about the visual and physical accessibility of the safety devices and components in the physical environment. While designing these components, these standards provide an understanding of the real-life components such as emergency buttons, safety mats, and safety gates so designers can use those physical appearances and visuals to guide their design processes.

2.4.1.4 ISO 9241-11:2018 - Ergonomics of Human-System Interaction - Part 11: Usability: Definitions and Concepts

This standard is a part of ISO 9241 series, which is discusses in the above sections, which focuses on defining the usability concepts to ensure the user-focused design. While designing for automation systems, or any system for that matter, user's satisfaction and design's effectiveness and efficiency should be kept in mind. Effectiveness can be described as the accuracy with which a user can complete a certain goal. Efficiency is the resources used to create the effectiveness for the completion of a task. In UX, this can be described as the number of steps that are required to complete a task, or perhaps the amount of space a component takes in order to be visible and accessible. Satisfaction is the comfort or satisfaction a user feels after using the system. In the case of safety components, satisfaction could be the trust in the operator have in the system that it will effectively alert them in case of any emergency.

3 STUDY APPROACH AND METHODOLOGIES

The methodology section lays down the approach and processes that were used to design and validate the safety components. Human-centred design (HCD) approach was used to facilitate the design cycle. Human-centered design approach for developing interactive systems keeps the focus on users to design a system that is efficient and useful for the user (International Organization for Standardization, 2019). The HCD process defines five primary phases for the development cycle to achieve optimal results. These five primary phases include discovery, ideation, concept validation, iteration, and implementation (Montalbano & Lehman, 2024). The first step in designing the safety components was to understand the requirements from the perspective of product owners and engineers to grasp the concept of safety components in Valmet's DNA UI. The discovery phase included a pre-study with a focus group and three separate interviews with industry experts and UX designers who have previously worked with safety features for Valmet's DNA. In the case of safety components, it was crucial to understand the requirements entirely so there is minimum room for error.

Once the problem was clearly defined, the next step was to start planning the design process. That meant understanding the existing component guidelines, creating new guidelines if necessary, and creating a step-by-step process for the design approach. An independent design approach was used for the design process, which means working independently to do the background research, discover existing internal artefacts, create the initial wireframes and document the specifications (Montalbano & Lehman, 2024). Additionally, the product owners were kept in a loop to ensure the concept wireframes followed the discussions and met the requirements. Since the safety components were not being designed in a vacuum just for the thesis but were part of an actual project, it was easy to gather early feedback from the product owners due to their interest in the success of the safety components. In a sense, the designing and expert validation went hand in hand.

The next part of the process was to specify the first few safety components: the emergency stop button, safety gate, safety mat, and start-up prevention. Before doing any design validation with the on-field operators, internal reviews with the product owners were necessary to ensure the safety components met the basic requirements and their vision.

These reviews happened as a regular part of the agile development process in the "concept validation" phase (Montalbano & Lehman, 2024). The specification documentation was created according to Valmet's documentation practices. These specifications contain details from the fundamental functionality to the functional tags and logic that the product owners or engineers add to the specification.

The next part of the HCD process was to validate the solution with the on-field operators. The mixed method research strategy was used to gather the operators' input regarding the proposed design. The surveys were used as qualitative research methods alongside the interviews to enhance the richness of the data collected. Surveys as a qualitative research tool provide a few advantages when paired with interviews to gather rich participant data. Harris, L., & Brown, G. T. L. (2010) provide a brief guide on pairing surveys and interviews to collect rich and meaningful data. Braun et al. (2021) report the success and a brief guide on preparing such surveys to gather meaningful data in their study. They concluded in their study that the participants preferred shorter qualitative surveys that gave more detailed answers. The longer surveys get more ambiguous results and only seem to work in qualitative research (Braun et al., 2021). Harris, L., & Brown, G. T. L. (2010) concluded in their research that when mixed research methods are used, the data must be collected in a short period. Another benefit of the mixed research method is the ability of the participant to take their time filling out the survey without feeling pressured to complete it in a specific time. It also allows the participants to answer the surveys more truthfully and unbiasedly (Dillman et al., 2014). This method was adequate for this research since the surveys and interviews were conducted simultaneously. The survey questions were designed to understand whether the on-field operators would be able to understand the situation just by looking at the safety components or not. The upcoming survey section will discuss the survey questions more.

The interviews were conducted to elaborate on the survey questions. Oishi (2003) provides a concrete guide in her book on writing down questions for the interviews and surveys and creating a relationship between the two. She guides the use of a language that is relevant to the population, which is why it was decided to conduct the interview in Finnish rather than English. The interviews were conducted by Jukka Järvelä, a UX designer working in Valmet’s R&D and later notes were translated to English for the analysis. Moreover, this also applies to the field's language; it is essential to use the terminology these operators use to avoid any confusion. Oishi, S. M. (2003) also advises using neutral and unbiased language to avoid influencing the participant's answer. She also encouraged the use of visual aids as a recall method, which aided the interview session since most of the questions were regarding the designs they saw while filling out the surveys. Comprehensive notes were taken during the interviews to analyse and match the data with the survey data. The interview questions expanded on the survey rather than being a separate entity. Multiple data analysis tools were used to analyse and understand the data. Thematic analysis was used to find common themes in interviews and focus groups. Thematic analysis is a quick way to divide the data into relevant groups with a visual understanding of the data (Rosala, 2022). The survey data was also considered while creating the themes since the survey had some open-ended questions related to the proposed designs. The thematic analysis provided an overview of the research results, and the research outcome was quite evident.

4 PRE-STUDY

The pre-study phase is a crucial part of analysing, defining and gathering information regarding the research. Pre-study provides a groundwork for research and is crucial to design the study itself (Ghosh, 2018). The pre-study phase identifies any uncertain factors and challenges related to the study early on. The pre-study was designed to understand the requirements for the safety components. As UX designers, it is essential to grasp the basic concepts first rather than jumping straight to the design process. Moreover, it was necessary to understand the current implementation of safety components, and the understanding of designers, as well as product owners to comprehend the next steps and design the study accordingly. Since safety components are used in almost all the different projects, it was crucial to understand how each project is handling them. Pre-study phase also involved a deep dive into the literature, which mostly included internal meeting notes, previous research done by Valmet, and ISO standards. Combining these with focus groups and interviews provided a lot of qualitative data that helped understand the current implementation of safety components and their future requirements.

4.1 Focus group

A focus group is a way to gather qualitative data related to the research topic. A focus group involves a group discussion guided by a host to understand the already existing knowledge possessed by the field experts or end users depending on the requirements of the study. Focus group allows the participants to discuss the topic from different perspectives due to the diverse backgrounds of the participants. These diverse viewpoints can uncover insights which might not be possible during individual interview (Kitzinger, 1994). The focus group was designed to ensure that the conversation is not between the host and the participants but between the participants themselves (Morgan, D. 1997). This method is explained by Morgan (1997), who states that the purpose of the focus group is to develop conversations between participants to generate ideas. The host's job should be to observe the conversation, take notes, if not recorded, and guide the conversation if it goes beyond the scope of the topic (Liamputtong, P, 2011).

The primary purpose of this focus group was to understand the context of safety components in depth. The participants for the focus group were chosen to drive the conversation from different perspectives. Three participants were chosen from different departments and different products. Two of the three participants were senior project engineers from different projects and one of them was a lead engineer. The unstructured interview approach was adopted to let the conversation flow without any constraints. The focus group was intended to last for two hours; however, it went overboard. The focus group helped grasping the technical details of the safety system, which in turn improved the understanding of how safety components work. It was crucial to understand the technicalities and limitation to avoid designing unattainable components. After discovering the use of safety components across multiple projects, it was clear that re-design is necessary for consistency, accessibility, and efficiency.

4.2 Pre-study Interviews

Just like focus groups, interviews are also a crucial method to gather qualitative information at any stage of the study. For this study, the purpose of these pre-study interviews was to gather further insights regarding safety components, recognise the underlying issues that call for a re-design, talk to the industry experts who conducted previous research regarding the topic, and to refine the research questions. Five semi-structured interviews were conducted with four participants. These participants included two product owners, a senior UX designer who led previous research regarding safety systems, and the Valmet's UX lead. The purpose of these interviews was not to answer any specific questions, but to let the conversation flow to understand the findings of the previous research or work done by Valmet. Since all participants were Valmet employees and understood the scope of the research, the conversation stayed relevant despite it being un-structured. The interviews were conducted remotely using Teams and thorough notes were taken digitally.

4.3 Pre-study results

The pre-study findings were analysed using the thematic analysis. All the relevant topics that came up during the interviews and focus group were divided into different categories. By doing so, the themes were recognised, and it was easier to find the most relevant themes and move forward with them. Following are the key discoveries made as the result of the pre-study.

4.3.1 Discrepancies in Safety Component Designs

The pre-study quickly revealed various concerns regarding the current implementation of safety component. One of the said issues was the discrepancies in safety component designs across the projects. Different projects were using their own designs based on the component guidelines available to them. Although, component guidelines provide a baseline for the design, it certainly does not mean that the result will be the same for every designer. Designers can use same guidelines and can end up with entirely different looking components. Such inconsistencies can be dangerous since they make it possible for operators to misinterpret the components. Moreover, a few projects are using their own interpretation of how a safety component should be without any input from the UX designers, which means there are chances of visibility and accessibility issues in the designs. Following is an example of discrepancies in safety components. The design difference can be seen between the different projects while comparing the figure 12 and figure 13. In the first examples, the project is using their own design for safety components created by the UX designers in Jyväskylä office. Although, it is acceptable for different projects to use their own designs; however, the designs must follow the component guidelines. In the first example, the designs are breaking a lot of component design principles, creating inconsistencies in the design. However, the second example shows the re-designed safety component (emergency button), which follow the design principles. Regardless of the design choices and subjectivity of design, the need to have a consistent design is crucial and must be the highest priority.

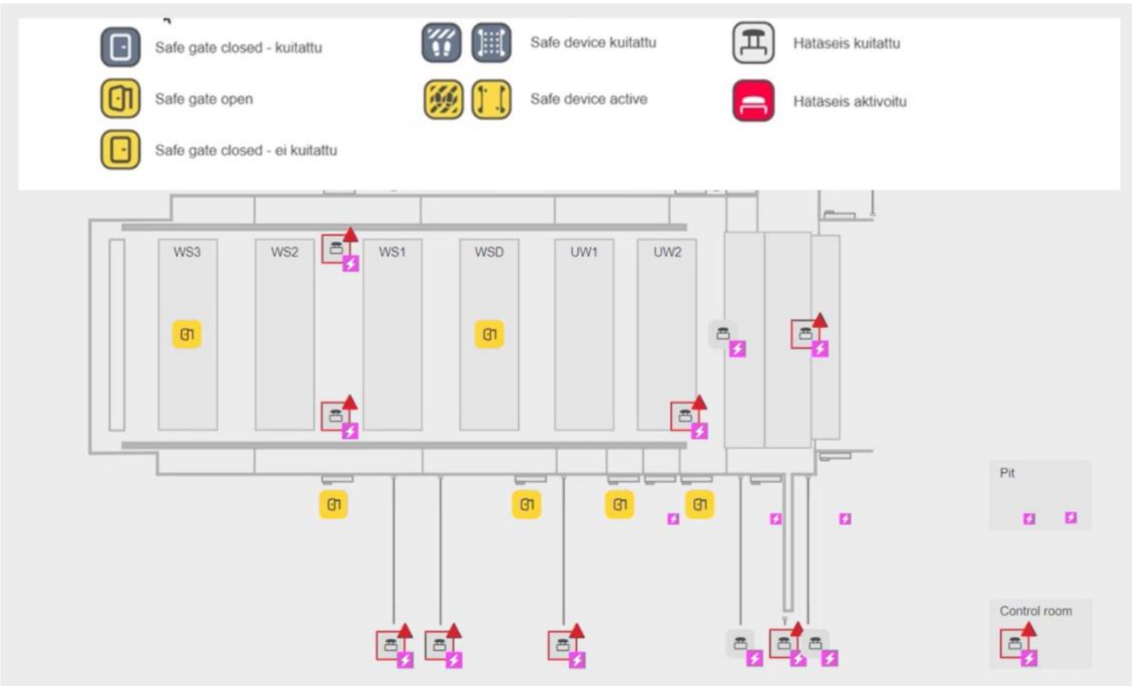

Figure 12. *Safety components in MCS Tissue*

Figure 13: *Safety components in Drives*

4.3.2 Need for Consistent Design and Better Guidelines

The existence of inconsistencies in designs highlights the need for standardised design guidelines across all projects. Although, such guidelines already exist, all designers must be made aware of them and encouraged to use them for consistent designs. Consistency in design is crucial, especially when it comes to safety components due to their importance in the automation systems. Consistent designs can guarantee that operators will have high chance of recognising the similar looking component, not matter the product they are working with. Using standardised guidelines also means that all the designs will follow same principles and visual conventions, making it easier for developers to reuse the code. Moreover, many projects use similar or same safety component, which means these components can be in a common library and each project can use the same library of safety components to reduce redundant work.

4.3.3 Necessity for Re-design to Enhance Visibility in UI

Although safety components already exist in Valmet's UI, the pre-study concludes that a re-design is necessary for some projects to improve their visibility in the UI. Some UI elements, which are not directly related to safety components, but can still cause confusion and risks were identified and need further discussion, which is out of this thesis's scope. Such findings, though not a part of this thesis, still should be a priority at this moment. Moreover, some indication that are utilised to notify operator about abnormal situations are not distinctive enough. For example, the indication for safety interlocking and normal interlocking are not very distinguishable and can be misinterpreted easily. Figure 14 shows the indications for normal and safety interlockings for visualisation.

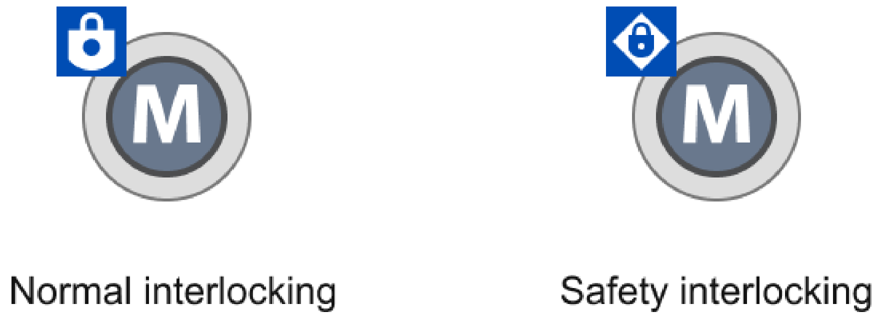

Figure 14: *Normal vs safety interlocking*

When there are quite many components on a page, their visibility decreases, which means it becomes difficult for the operator to perceive what kind of interlocking is affecting the component. Regardless of the external factors, the symbols for these two different kinds of interlocking should be distinct enough for the user to interpret the situation in a glance.

5 DESIGNING SAFETY COMPONENTS

Pre-study cleared the requirements for the safety components. While designing the components, the guidelines seemed to be able to support the safety components as well. The first step in designing the safety components was to lay down the requirements and start brainstorming. After pre-study, following points were kept in mind while designing the safety components:

- Similarity to the normal components when in non-actuated state.
- Clear distinction from the normal components when in the actuated state.
- Communicate the emergency through visual clues.
- Try to use already available component items to design safety components.
- Universal design for safety components so they can be used by all projects.

5.1 Brainstorming

One of the starting steps in designing the safety components was understanding the situations and scenarios in which these components will be actuated. For example, if a safety gate has failed to lock, and a machine cannot start unless that door is closed, it is not a huge issue since the machine will not start unless the conditions are safe. In those cases, milder approaches can be used to show the actuated component. However, if something goes wrong while the machine is in the production mode; in that case, it is essential that the machine is stopped immediately, and appropriate actions are taken.

One of the significant ideas that stuck throughout the design process and iterations was provided by Anni Uusitalo, who is a fellow UX designer at Valmet. In the initial designs, a black and yellow striped ring was added to the outer frame of the component. The inspiration was taken from real-life danger zones that use black and yellow stripes on the floor, doors, or ribbon form to indicate danger and caution. These black and yellow stripes are widely used and understood by factory operators and ordinary people.

International Organization for Standardization (2011) provides a comprehensive guide on symbols and safety markings to be used for different scenarios. For example, yellow/black markings should be used to indicate hazards, red/white markings should be used to indicate firefighting equipment in prohibited zones, green/white markings for safe conditions, and so on. Though these markings and standards are meant for the physical environments, these rules can still work for a user interface. Using already existing mental models can be a great way to ensure good communication through design that aligns with the user's expectations (Nielsen & Chan, 2024).

Using said black/yellow stripe would also mean that the design would not have to be changed much and can rely on the outer ring to represent the danger using the black/yellow stripes. This meant that when safety components are not actuated, they will resemble the normal components and not take away the operator's attention from other vital tasks/information on the screen. However, when they are actuated, these safety components will immediately grab the operator's attention with their prominent outer-ring and the pop of colour. In Valmet's UI, one of the principles is to always use colours for a specific reason. The UI itself does not support many colours unless they are used to highlight something important. The use of colours is limited to alarms, trends, measurements and other tools where values need to be differentiated using colour. The dark and light greys are used for most of the components and figures on the page level. So, whenever an alarm or unusual activity happens, the operator's attention immediately follows that.

5.2 Normal component design

As briefly discussed previously, the normal components on Valmet’s automation UI consist of various items, i.e., component ring, component symbol/icon, background, operating mode indication, alarm and fault notification, etc. However, not all these visual components are always used, their usage depends on the situation and their need. For example, not all components have the operating mode indication and not all components have outer-ring measurement. These things can be enabled or disabled in Valmet’s UID (user interface designer).

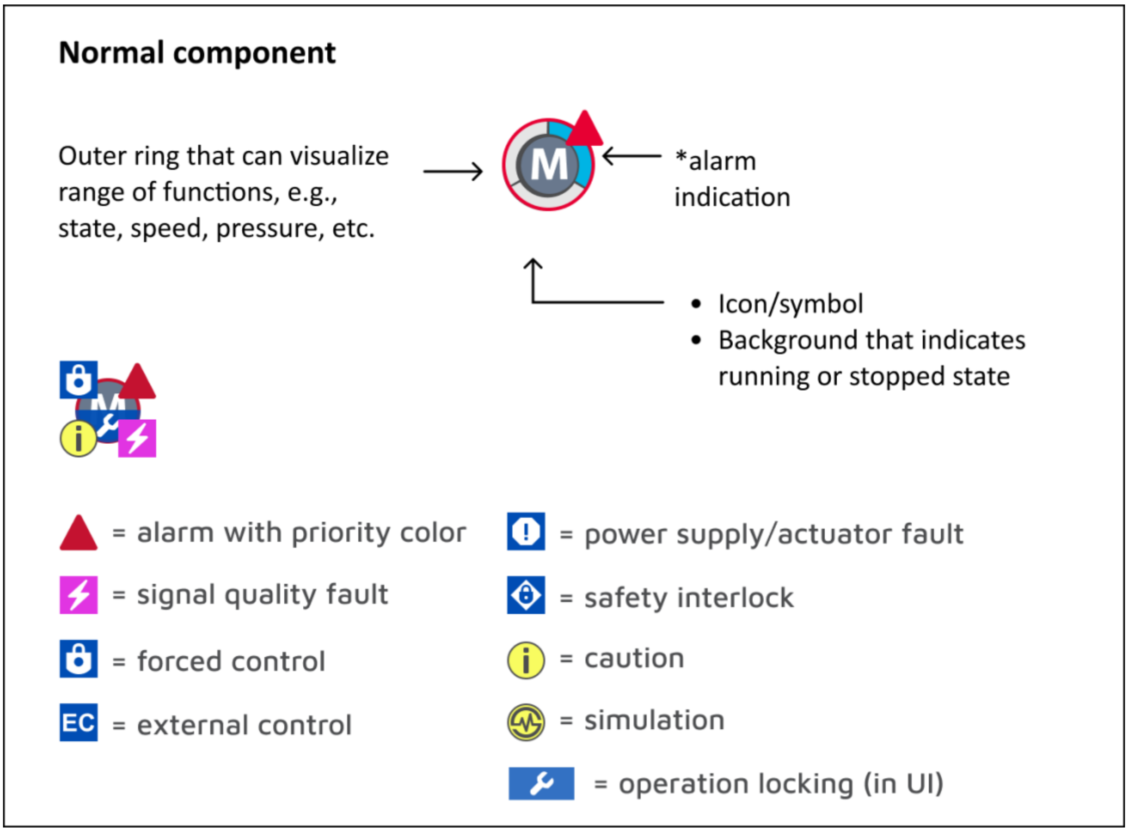

Figure 15: *Normal component design*

Using normal components as a baseline helps with the consistency across the projects. Normal components have a mature design in Valmet's UI and the guidelines are followed across the projects. Various components already have templates and exist in Valmet's UID libraries that can be used by UI designers to reduce redundant work. The components are recognisable across projects and cannot be mistakes for something else. Hence, using normal components as baseline ensures that designs follow the design principles forcing all the projects to use the same designs for their safety components as well.

5.3 Safety components design

To design the safety components, a few guidelines were created to streamline the process. The information during the pre-study phase helped create these early guidelines to help rationalise the design process for the safety components.

5.3.1 Black/yellow stripes

It was evident that the black/yellow stripes would be the best way to indicate the emergency as previously discussed in the section 3.2.1 (International Organization for Standardization, 2011). The design principle 7: "using the component frame" allows the use of stripes in the outer ring of the component to show the emergency state. On-field operators are familiar with black/yellow stripes since they are used to highlight the danger/caution zones. It meant that even if operators are not familiar with these safety components, they will at least be able to understand the situation without having any prior knowledge. Using these stripes will be limited to emergency situations; however, not only to safety components. For example, the equipment that can potentially endanger a human life, when in that state, should also be considered a safety hazard, hence, use of these black/yellow stripes. So, in a way, this principle was not only limited to safety components but could be utilised in other critical situations as well. Figure 16 shows the example of the safety gate component to illustrate the use of black and yellow stripes.

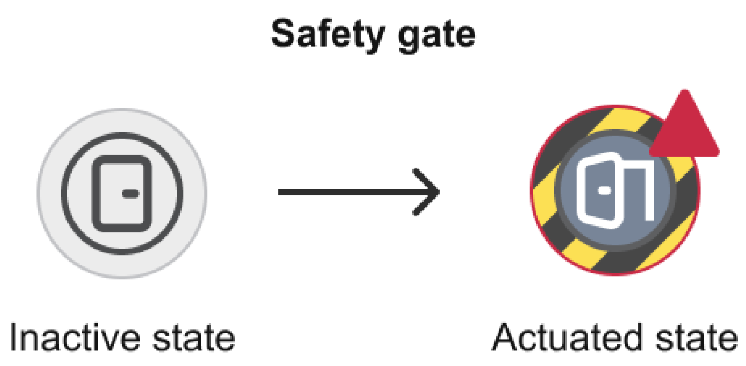

Figure 16: *Safety gate example*

5.3.2 Component Background colour

Normal components have two background colour options, dark grey and light grey. The colour of the background depends on the state of the component. If the component if running or in an active state, the background is set to dark grey to indicate the running state. Similarly, when the component is not running, or is in the inactive/rest state, the background is set to light grey, which is also called non-filled background to indicate the inactive state of the component. These backgrounds provide an intuitive way to understand the state of the components in a quick glance.

However, due to the different levels of criticality in safety components, new background colours were introduced to differentiate between them. Currently, two background colours are available for safety components; red, and dark grey. The dark grey colour is the same as normal components, in that case the differentiating factor for the safety components would be the black/yellow outer ring. However, in the case of red, the differentiating factor is both the colour of the background and the outer ring. The red background is used to indicate the higher-level emergency situations; for example, if an emergency button is pressed in the facility. For now, only emergency button has the red background since that is of the highest priority. All the other safety components have dark grey background since in most cases, they do not cause harm to human life. In many cases, the machines do not start if such components are not in the normal state already. For example, if a safety gate is not properly locked, the section of the machine to which the safety gate belongs will not start and show a safety interlocking symbol to indicate the issue. Figure 17 shows the main design choices for the safety components.

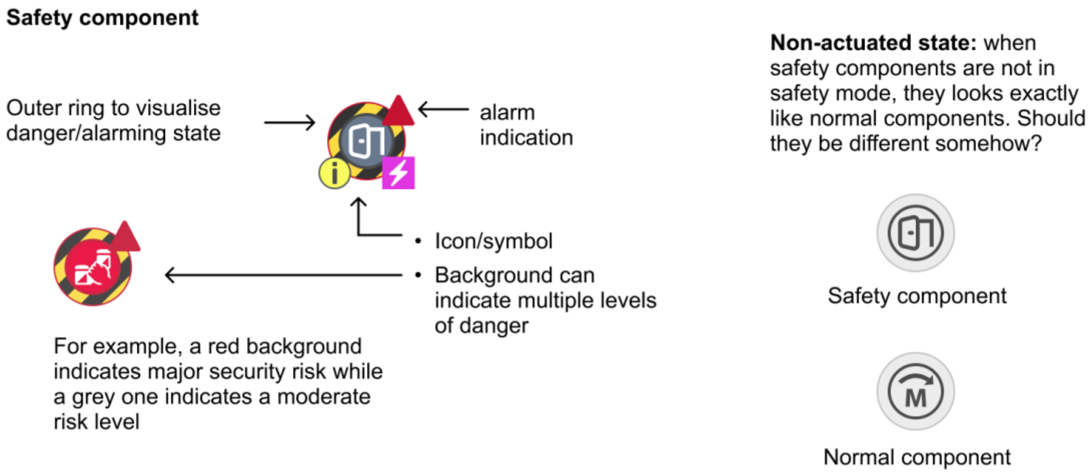

Figure 17: *Safety components*

6 VALIDATION

The next step in the process was to validate new designs with field operators. This step was crucial to validate whether new designs fulfil the real-life requirements for safety components. Validation process is a key phase of user-centred design (UCD), to ensure that the theoretical designs provide expected performance when interacting with end-users in real-life scenarios. This chapter highlights the methodologies used to validate the designs and their results. These finding are crucial for this research to understand the effectiveness of these components in communicating the emergency situations. For the validation process, a combination of surveys and post-survey interviews was used to gather qualitative data. After data collection, the results were analysed, and thematic analysis was done to find the common themes amongst the participants. The details are already discussed in chapter 3: Methodologies.

6.1 Surveys

As previously discussed, the surveys were used as a qualitative data-gathering tool rather than quantitative. Surveys are an excellent tool to gather situational information without having any input or influence on the participant's answers (Braun et al., 2021). The survey aimed to gather data on the usability and communication of the safety components from the operators. The survey was deliberately designed to evaluate whether operators can understand emergency situations accurately without prior knowledge about the newly designed safety component. Questions were structured to evaluate recognition, knowledge, and response to the redesigned safety components. The survey included multiple-choice and open-ended questions to capture a range of responses, insights, and comprehensive data (Dillman et al., 2014).

The survey and interviews targeted on-field operators at the Kemi, Finland, location. This study's target audience included operators who had no prior knowledge of the new safety components. Finding operators who fulfilled this criterion was crucial to ensuring unbiased responses since validating the design was the whole purpose. According to Fowler (2014), selecting a representative sample is crucial for acquiring accurate and reliable data in survey research. A representative sample ensures that the findings can be generalised to the broader population of operators, grasping a wide range of viewpoints and experiences. Refer to the appendix 1 to see the full-length survey.

The data was collected by surveying ten people who met the selection criteria. The surveys were conducted in a controlled environment within the Kemi facility. As discussed earlier, the length of the survey was short since the situational questions were asked, which can take some time to think about and answer. The survey was designed to be completed within ten to fifteen minutes. As guided by Groves et al. (2009) in their book 'Survey Methodology', ensuring a manageable length for the qualitative surveys helps maintain the participant's attention and engagement and reduce the likelihood of incomplete responses. The survey consisted of eight questions, five of which were situation questions, two of which were multiple choice questions to understand their perception of the safety components and one open-ended question. The survey questions focused on multiple vital areas:

- **Recognition:** evaluating whether the operators can correctly differentiate the safety components from the normal components.
- **Interpretation:** assessing whether the operators can understand and interpret the situations accurately, particularly in emergency situations.
- **Response:** evaluating the operator's confidence in reacting to the actuated safety components and their perceived effectiveness of the visual cues.

Each question had a purpose in the survey; the intention was to understand whether our design makes sense in the system and whether it integrates well with the other UI components. Reviewing the questions would help understand their purpose and reasoning behind them.

> Question 1: "Can you differentiate between a normal component and a safety component in Valmet UI?"

The purpose of this question was to understand whether the operators can differentiate between the normal components and the current implementation of the safety components. The implementation of the safety components, at the time of the surveys, in the Kemi facility were done independently by the engineers without any UX study or input. These components are not as intuitive when it comes to communicating the emergency situation. However, the operators are familiar with them because they have been using them for a while. In many cases, the old components are limited to only maintenance and emergency pages in the UI. The aim of the question was to understand whether operators know about the current implementation of safety components. Figure 18 shows the question 2 visuals from the survey.

> Question 2: “Looking at the appearance, can you differentiate between safety component and a normal component? Choose the normal component.”

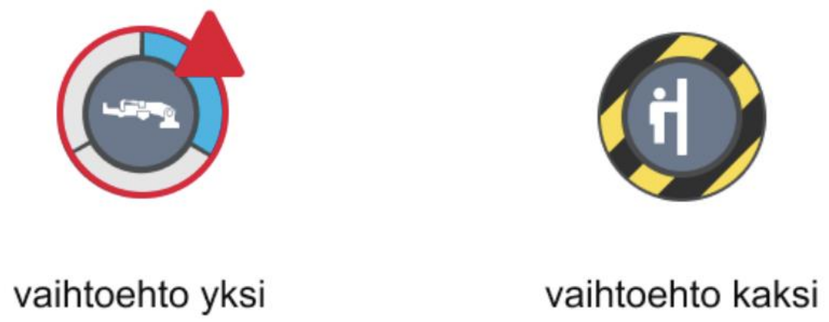

Figure 18: *Survey question 2*

The purpose of this question was to understand whether operators can differentiate between normal components and new safety components without having any prior knowledge about the new designs for the safety components. The trick here was that the normal component was alarming; hence, it had an alarm indication with a red-coloured border. Meanwhile, the safety component, though it was actuated, did not have an alarm indication or red border. In some cases, the safety components might be in an "unsafe" state but are not alarming. These states can be, for example, a maintenance operating mode when the equipment is in maintenance and needs special care. The idea was that the operators might confuse the alarming component with the safety component. Figure 19 shoes the visuals for the question number 3.

> Question 3: “Can you select the safety component from the following options”

Figure 19: *Survey question 3*

In this case, both safety and normal components were alarming, with a red-coloured ring and an alarm and caution indication. This question aimed to understand whether operators can differentiate between the safety and normal components while in an alarming state. It should not be easy for the operators to confuse between the two.

> Question 4: “What do you think makes a safety component different from a normal component?”

This question was an open-ended one. The reason for positioning this question here was to understand whether operators are picking up on visual clues about safety components. The optimal answers to this question would be "black/yellow stripes" or "warning/danger zone markings" since that was a visible differentiating factor between the normal and safety components.

> Question 5: “When you think of a safety component, what colour do you think about?”

The aim of this question was to understand whether the design choices follow the mental models that the operators might already have. It was a multiple-choice question with four options: yellow, red, orange, and grey. One limitation of this question was its position in the survey. The previous questions might have had an influence on the participants’ answers. This question also aimed to evaluate operator’s colour association with the safety components, which is essential for designing intuitive and immediately recognisable components. Figure 20 shows the visual of the question 6 in the survey.

> Question 6: “Which one of following do you think is a safety component?”

Figure 20: *Survey question 6*

This question was tricky, considering both components shown were safety components. This question aimed to understand whether introducing another background colour might be confusing. For example, the red-coloured background is only available for emergency buttons because they have the highest priority when it comes to safety components. However, the operators might think that the component with the red background is the only safety component.

Question 7: "Which one of the following is indicating the safety interlocking"

Figure 21: *Survey question 7*

This question was related to the issue discovered during the pre-study phase. The normal and safety interlocking indications are quite similar and easy to confuse (see figure 21). The aim here was to evaluate if operators can easily differentiate between the two. Both indication symbols have been in use for a while now, so it would be easier for the participants to differentiate them; however, if they cannot, then it could be a considerable issue as safety interlockings should be quite easy to recognise.

Question 8: "How would you interpret the following situation"

Figure 22: *Survey question 8*

This scenario-based question was designed to test the operators' current knowledge regarding safety interlockings (see figure 22). When a safety component is actuated, for example, an emergency button, then the components/equipment affected by it should indicate the safety interlocking symbol. The operators were given following multiple choices to choose from:

- Both are safety components that are in alarming state
- Emergency button is pressed hence motor has stopped because of the safety interlocking
- Emergency button is pressed, and motor is alarming. Both situations are unrelated.
- Other

Out of these, the second option was the correct one. In this scenario, the emergency button is pressed, and the motor is stopped because of the safety interlocking related to the emergency button.

The survey was taken on printed paper, and the answers were manually transferred to the Microsoft forms afterwards. The qualitative data from the open-ended questions was analysed using the code method to identify common patterns. Moreover, thematic analysis was done for the qualitative data from the open-ended questions to understand the participants' insights and understanding of the components (Creswell, 2014). This practice is supported by the work of Creswell (2014), who emphasises the significance of mixed-methods research in delivering a thorough understanding of research questions. Prior to the study, the operators' consent was obtained to use this data for the thesis, and their confidentiality and anonymity were promised per the EU General Data Protection Regulation (EU-GDPR).

6.2 Operator interviews

The validation phase included semi-structured interviews as well. The purpose of these interviews was to expand on the survey and gather in-depth data regarding the thought process of the operators while filling in the survey and their opinions about the designs. The interviews were conducted from the same people who participated in surveys. The interviews were conducted right after operators handed in their surveys to ensure the use of their fresh memory of the survey. The interviews were conducted in Finnish, since operators speak and use Finnish in their daily work. The aim was to gather qualitative data about the effectiveness and efficiency of the safety component's design from the people who would be using them on daily basis. The operators at Kemi facility were not familiar with the new safety components' design, which was the ideal scenario for this validation process. The purpose of the research was to understand whether it is possible for operators to recognise and understand the emergency just by looking at the components. Since, operators were unaware with new designs, it was a perfect opportunity to validate whether designs are accurately communicating as intended. The semi-structured approach was used to take advantage of the flexibility it offers when it comes to the open-ended question. This approach allows for consistency across the interviews while adding the opportunity to gather rich and detailed data (Cohen & Crabtree, 2006). Semi-structured interviews are beneficial when used with surveys, as they can provide deeper insights and explanations for the quantitative data gathered in surveys (Johnson & Turner, 2003).

The interview questions were designed based on the initial survey to further explore the answers provided by the participants. A few structured questions were asked from all the participants to keep some sort of consistency and to have a focal point for the interviews. For example, the following fixed questions were asked of all the participants:

- "Were you able to identify any safety components in the survey? If yes, please point those out for me."
- "What do you think a safety component is?"
- "Do you think the current safety implementation of safety components is sufficient?"
- "What do you think about the proposed design for the safety components?"

Once these questions were answered, the plan was to ask relevant open-ended questions related to the answers provided by the participants. Following are some of the questions that were asked by the interviewer:

- You mentioned that you were able to differentiate between normal and safety components. Can you describe what specific visual elements helped to differentiate between the two?"
- "Can you walk me through your thought process about the emergency situation scenario in the survey?"

- "Can you elaborate on why you think yellow/orange/red/blue should be an effective colour for the safety components?"
- "What do you think about the normal and safety interlocking indications? Do you think they are clear enough for you to distinguish between each other?"

These questions helped elaborate on participants' thought process behind their answers. Thorough notes were created while interviewing the participants, and the answers were included in the thematic analysis.

6.3 Data analysis

The collected data from both surveys and semi-structured interviews were analysed using thematic analysis, a qualitative method for identifying, analysing, and reporting patterns (themes) within data. This approach is particularly useful in qualitative research for uncovering rich, detailed insights and understanding complex phenomena from the participants' perspectives (Braun & Clarke, 2006).

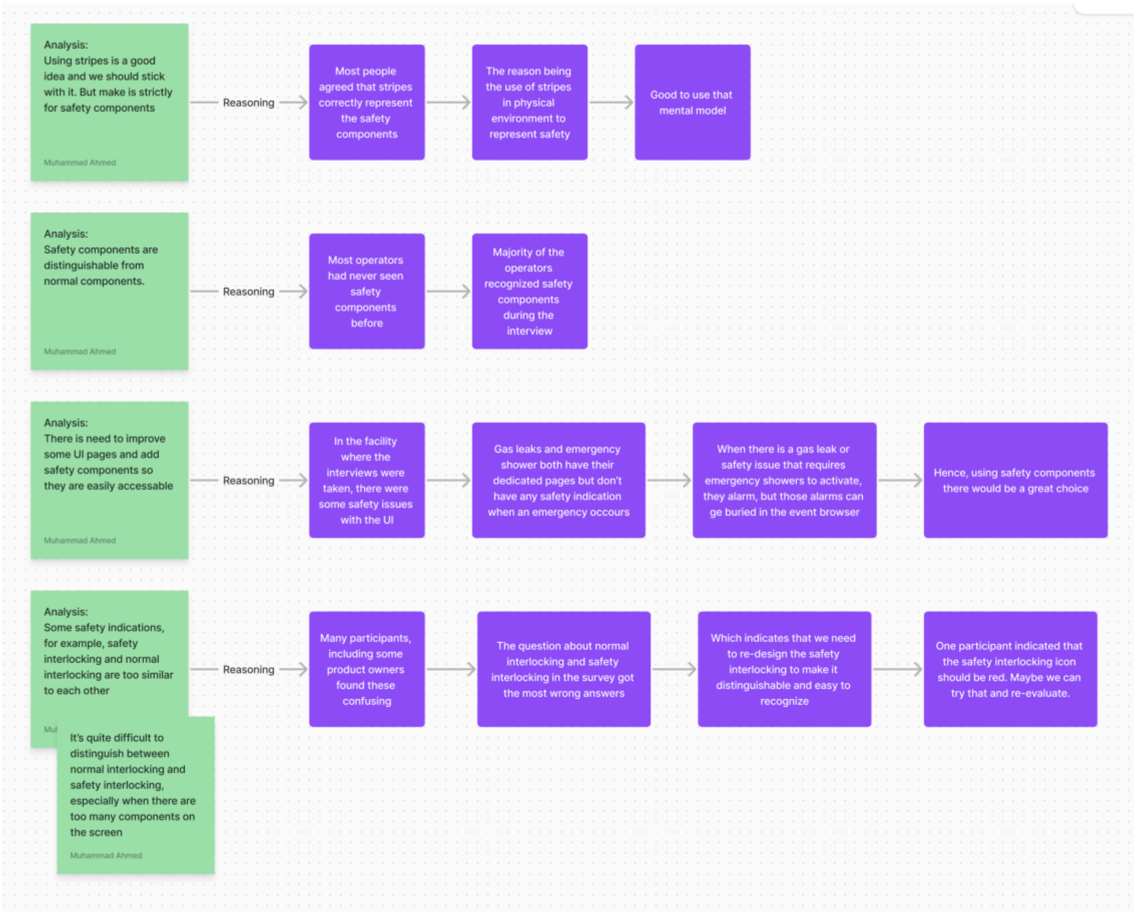

Figure 23: *Thematic analysis example*

The first step was to understand the collected data to move forward with the thematic analysis. The process of data familiarisation included deep dive into the interview notes, translating the open-ended questions, adding paper forms' data into Microsoft form, make sense of the survey data, and in-depth understanding of all the available content. Initial findings were discussed with the colleagues to ensure and validate the next steps for successful data interpretation. Figure 23 displays and example of the thematic analysis that was done during this phase.

The next step was to start generating initial codes for the data. While generating codes for the data, keywords like "security", "safety", "stripes", and "danger zones" were identified. At this point, no themes were considered and quotes from the operator interviews and surveys were categorised into these codes. The purpose of this exercise was to generate initial categories for the data before recognising the themes. Without these codes, it was difficult to read through data and keep track of what keywords might appear in the quotes. Moreover, the codes were used loosely, meaning their quotes with related words were also added to these categories instead of looking for the exact keyword.

After categorising the quotes, it was time to recognise themes in the collected data. Categorised data might have quotes with a certain keyword, but it could be talking about something completely different. While analysing the data, various themes were recognised; including, "using black/yellow stripes", "recognition of safety components", "need for improvements", and "lack of distinction amongst some symbols". These themes were a common occurrence in the data and provided an overall idea of how well operators perceived the newly designed components. After analysing the themes, an internal report was created to understand the results in depth. This report included a detailed description of each theme, supported by direct quotes from the data to illustrate the themes. This narrative provided a coherent and persuasive finding, linking back to the research questions and objectives (Braun & Clarke, 2006).

7 RESULTS

The results section focuses on the findings from the validation phase, focusing on evaluating the effectiveness of new designs of safety components. The results section presents both qualitative and quantitative data collected during the validation phase in the form of surveys and post-survey interviews.

7.1 Survey results

Survey results were straight forward to interpret due to the simplicity of the survey. The survey questionnaire was designed to simply understand whether newly designed safety components are descriptive enough with their designs to communicate the emergency situations to operators. A majority, 8 out of 10 of the participants were confident that they will be able to differentiate safety components from the normal components. This conclusion was derived from the first question of the survey which asked, “Can you differentiate a normal component from a safety component?”. The purpose of this question was to understand participant’s current understanding of the safety components.

When presented with two components (see figure 15), one of which was a normal component and the other was a safety component, 6 out of 10 operators selected the correct option and recognised the safety component. However, when another question of the same nature was asked (see figure 16), 9 out of 10 participants were able to recognise the safety component successfully. The difference between the two questions was the status of the components. In the first question, an alarming normal component was shown with an unalarming (in a normal state) safety component. However, in the second question, both normal and safety components were alarming. In another question, two safety components were shown to the participants (see figure 17) and they were asked to recognise the safety component out of them. In response to that, 7 out of 10 participants were able to recognise both as safety components.

When asked, "What do you think makes a safety component different from a normal component?", a popular answer was “black and yellow stripes”. Other replies to this question were “Musta Raidoitus”, “Kelta/Musta”, “punainen”, “Lukko”, and “Huomio raidat ja värit”, which means “Black stripes”, “Yellow/Black”, “Red”, “Lock”, and “Pay attention to the colour” respectively. When asked about the colours they associate with safety components, red was the most popular choice with 8 participants opting for it and yellow came second with 6 votes.

A question related to the safety interlocking symbols were asked. There are two different kinds of interlockings available in Valmet's automation system (see figure 18). The interlocking symbols represent either the normal interlocking or safety related interlocking. During the pre-study phase, it was discovered that these interlocking symbols are not distinctive enough, which is why this question was added to the survey. Only 5 out of 10 participants were able to recognise the correct interlocking symbol.

A situational question was included in the survey to evaluate whether participants will be able to understand the situation just by looking at the visuals. The question showed a situation in which an emergency button is pressed, resulting a certain motor to stop working (see figure 19). As a response, 8 out 10 participants were able to answer the question correctly and were able to understand the situation.

7.2 Interview results

Interview questions were asked right after participants completed their survey, so they have a fresh memory of survey questions. The purpose of the interview questions was to ask follow-up questions related to the answers provided by the participants in the survey. The interview was a semi-structured interview and was conducted in Finnish by another UX designer at Valmet. The comprehensive notes were taken and translated in English for the analysis. Following are the key findings derived from the analysis of the interview notes.

When asked "what do you think a safety component is", majority of the participants answered, "black and yellow stripes". Just like the survey, some other answers included phrases such as "red colour", "stripes", "zone sign", "lock", and "colouring of the component". When asked to elaborate on why black and yellow stripes are a good choice to visualise the safety components, majority of the participants referred to the real-life danger and warning zones. They agreed that using same colours as real-life environments helped them recognise the safety components correctly.

Another important aspect of the interviews was to understand the operators' standing on the new designs. When asked about whether newly designed safety components are self-sufficient or not, 9 out of 10 participants agreed that they were able to recognise the safety components easily. However, when asked to elaborate on the safety interlocking symbol, all the participants agreed that the normal and safety interlocking symbols were quite difficult to differentiate, and they did not feel confident while selecting the correct symbol during the survey.

8 DISCUSSION

The discussion section will talk about the overall outcome of the research and any limitations that this research might have. The discussion section will focus on the critical examination of the findings presented in the result section. This chapter interprets the results collected from surveys and interviews and speaks about their implications. The comprehensive analysis of the survey and interview data yielded several key findings, highlighting the effectiveness and usability of the redesigned safety components in Valmet's automation systems.

8.1 Research outcomes

A majority of the participants claimed that they can differentiate safety components from normal component, without having seen new safety component designs. This reflects their trust and confidence in the system. At the time, safety components did not have a visual representation in the facility but rather had alarm notifications to display any emergency situation. Which means, if an emergency button was to be actuated, all the components effected by that emergency button will stop working and display an alarm notification. A major issue with this approach is the lack of visibility and information when something goes wrong. An operator must click on the component, open diagnostic tab and then understand what is wrong with the system. Even after going through these steps, the operator still doesn’t have any information about which safety component is actuated and where in the facility. Using newly designed safety components will provide visualisation for the safety components themselves and all the information regarding their location and reasons for actuation. When safety components were shown to the participants, 8 out of 10 participants were able to recognise them as safety components. Multiple safety components were shown across multiple question and majority of the participants were able to recognise them and chose correct options. We can conclude from these results that new designs for safety components are descriptive enough for operators to immediately recognise them.

While analysing the data, it was recognised that majority of the participants think that using visual cues, particularly black and yellow stripes is a good idea. Participants agree that these stripes make safety component recognisable and distinguish them from other components. Majority of the participants concluded that the black and yellow stripes are easily recognisable as “safety concern” because they are used in physical environments for unsafe zones or for warnings. Using the same mental model makes it easier for the operators to understand the situation if an emergency were to happen. As mentioned in section 7.1, when asked, "What do you think makes a safety component different from a normal component?", a popular answer was “black and yellow stripes”. Although, this question was asked after an exposure of safety components to the participants in other survey questions. However, it can also be concluded from this result that participants were able to recognise the safety components just by looking at them in the survey questions. A few questions in the survey asked the participants to pick either a safety component or a normal component from the provided options (see section 6.1). These results we derived from an open-ended question, and some other answers were “Musta Raidoitus”, “Kelta/Musta”, “punainen”, “Lukko”, and “Huomio raidat ja värit”, which means “Black stripes”, “Yellow/Black”, “Red”, “Lock”, and “Pay attention to the colour” respectively. The above responses show the participants were already picking up on visual clues; hence, proving that the new designs were affective and clear to understand. The primary reason for this conclusion was the fact that participants were already mentioning some of the core design visuals for safety components e.g., stripes, red colour and lock icon. However, lock has already been in use for safety interlocking for a while now.

The results show a pattern of successful recognition of safety components. Most of the participants were able to understand the situation questions. Moreover, a majority of the participants were able to differentiate between safety and normal components over multiple questions. Questions 2, 3, and 6 in the survey (see section 6.1) asked participants to differentiate between normal and safety components in different ways. Question 2 was answered correctly by 6 participants, question 3 by 9 participants, and question 6 by 7 participants, showing that more than half participants were able to recognise safety components immediately after seeing them. Results also show the effectiveness of using colour in logical manner. As discussed in the background, Valmet’s UI use colours in a meaningful way. The UI does not have use bright colours to avoid drawing attention to them, unless that attention is exactly what is needed.

The new designs were based on already existing guidelines for components. The successful implementation and the positive feedback on these new safety components validate that the existing guidelines are flexible enough to support the development of new components. This flexibility is crucial for ensuring that design standards can evolve to meet new safety requirements and future development of new kinds of components.

The study also validated the concerns regarding the similar looking "interlocking" symbols. During the pre-study phase, it was discovered that the interlocking symbols for safety interlocking and normal interlocking are quite similar to each other and can be mistaken for each other. It is crucial that operators can differentiate between the two if they were to be actuated. The normal interlocking does not pose much of a threat and can only be critical for the production; however, the safety interlockings should be easily recognisable to avoid any harm that might come from the unsafe situation. For example, a part of a machine can be shut down due to a safety component being actuated. The affected components, e.g., motors, valves, etc., show an indication to represent such condition (see section 6.1-4). The survey result showed that half of the operators could not choose the correct option, and one operator argued that "safety indication should be red". This indicates that there is need to improve the interlocking indication and make them clear and understandable.

Although the outcomes of this thesis are formulated within the context offered by Valmet, the implications of the findings can be extended to cover safety components design and validation for industrial automation systems everywhere. The use of safety components, identified with descriptive visual aspects such as black and yellow stripes has to do with basic principles of human cognition and perception, as the following should apply to all industries aiming at increasing the safety of the actions and reactions of the operators in emergency cases.

The use of such qualities as color codes and symbols provides basic tools which can be put in practice to enable other organisations to enhance their human-machine Interfaces (HMIs). One example is:

- Availability of systematic visual designs in safety components prompts faster identification which lessens operational confusion and hasty reaction times.

By using mental paradigms such as demonstrating that yellow and black stripes stand for danger, makes use of very familiar signals throughout different cultures in the world. This technique can be employed in several industrial settings to enhance risk communications and decrease danger exposures.

This particular research also highlights the ability of established design criteria to integrate supplementary safety elements. The possibility to modify these guidelines without loss of the intended use also allows for a degree of implementation and integration into future developments of automation systems. Other than Valmet, other organisations can make use of this finding to make their processes on integration of new components more efficient but still consistent and user-friendly.

The results of this study extend to several sectors other than manufacturing, for instance, healthcare, transport, and energy among others where effective safety interface designs are required. One case in point is:

- Healthcare industry can adopt the same principles in the designing of safety alarms for critical equipment to facilitate quick identification of these alarms in a time of crisis.
- Another area of application is in transportation where users' interfaces of vehicle control systems can be improved by use of pictograms in enhancing safety for the operators and other passengers.

This thesis thesis addresses the global effort aimed at increasing safety and efficiency in industrial systems through designing of safety components, which are based on the users' needs. Its conclusions may be utilised as a base for further inquiries and enhancement in the design practices of safety-critical infrastructures leading to the development of much safer and efficient working environments.

8.2 Limitations

Although findings of this study have provided sufficient insights into the new safety components' designs, it is crucial acknowledge any shortcomings and limitation that may have impacted the study. This section discusses key constraints that were encountered during the research process, including factors related to the sample size, methodologies used, and contextual issues. These limitations will help any future research to focus on these areas to produce better results.

8.2.1 Sample size

One of the limitations that is apparent is the sample size and the location of the study. The validation process only included 10 participants who took part in surveys and interviews.

Moreover, all the participants were stationed in the same facility, limiting the diversity and experiences of the participants. Valmet has varied customers with different needs; hence, the future work would benefit from including participants from various sites and projects.

8.2.2 Focus on immediate usability

One of the shortcomings of this research work is the lack of focus on long term impacts of the designs. The focus of this research has been to validate whether safety components are recognisable by operators at first glance. However, there is a need to study the long-term usage and how these components will perform in production environment. Although the initial communication with these components have been validated, there is not guarantee that the components will perform as expected in the long run.

9 CONCLUSION

The main objective of the thesis was to design and validate safety components for Valmet's automation systems. The broader aim was to understand whether the existing component guidelines are enough for the creation of safety components without cutting any corners. To answer these questions, a comprehensive research approach was selected that included a pre-study, surveys, and semi-structured interviews to gather in-depth qualitative and quantitative data to validate the safety components' design. The safety components were designed by keeping UX guidelines and industry standards in mind to enhance their efficiency.

The study discovered that 80% of operators were able to differentiate safety components from the normal components. The survey results, combined with the interviews concluded the effectiveness of the new design for safety components. Moreover, the use of black and yellow stripes proved to be an effective solution for providing visual cues and differentiating safety components from other components, using the already existing mental models from real-word association with danger and hazard. The participants' comments regarding the use of black and white stripes solidified the decision to use them in the safety components.

Moreover, the study also validates the flexibility of existing guidelines which were originally created for normal components. The study shows that the guidelines are sufficient for safety components; however, more details should be added to the components for consistency between safety components. Currently, the component guidelines do not have detailed instruction on how to approach safety components. Although the guidelines are sufficient, the study also revealed inconsistencies across the projects. The reason for the inconsistencies was not the scope of this study; however, the future recommendation is to understand the reason behind the inconsistencies and promotion of guidelines across the projects.

In conclusion, the new design for safety components was validated as an effective approach for communicating emergency situations using visual cues. The study does not only validate the safety components, but also contributes towards the enhancement of

Valmet's product offerings and their safety. Moreover, the study allows for the betterment of existing guidelines for components and makes it possible for the designers to refine them and add details to support consistent and effective designs for safety components across the projects, making industrial environments safer for human life. Safety is a critical aspect of any automation system and there is always a need to improve the systems that are responsible for saving human lives. This research provides an insight on how to design safety components using examples from real-life environments to clearly communicate the emergency situations to the operators. This research not only benefits Valmet's own automation system but also provides insights on how to design safety components for the industry. The study contributes to the already existing UX design knowledge in the context of safety-critical systems and highlights the importance of using design elements from real life environments to drive mental models that users might already have. While this study focuses on the immediate recognition of the safety components, future research can focus on the long-term effects and usability.

REFERENCES

Braun, Virginia et al. “The Online Survey as a Qualitative Research Tool.” International journal of social research methodology 24.6 (2021): 641–654. Web.

Braun, Virginia, and Victoria Clarke. “Using Thematic Analysis in Psychology.” Qualitative research in psychology 3.2 (2006): 77–101. Web.

Campilho, R. D., & Silva, F. J. (2023). Industrial Process Improvement by Automation and Robotics. Machines, 11(11), 1011.

Canziba, Elvis. Hands-on UX Design for Developers : Design, Prototype, and Implement Compelling User Experiences from Scratch. 1st edition. Birmingham, England: Packt, 2018. Print.

Cohen, D., & Crabtree, B. (2006). Semi-structured interviews. Qualitative Research Guidelines Project.

Control Room Solutions - Valmet DNAe User Interface. (2024). Valmet.com. *https://www.valmet.com/automation/control-systems/user-interface/*

Creswell, John W. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. 4. Ed., Internat. Student Ed. Los Angeles, Calif. u.a: Sage, 2014. Print.

Dillman, Don A, Jolene D Smyth, and Leah Melani Christian. Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method. 4th edition. Newark: Wiley, 2014. Print.

Dong, W., Wang, Y., Zhou, Y. *et al.* Soft human–machine interfaces: design, sensing and stimulation. *Int J Intell Robot Appl* **2**, 313–338 (2018). https://doi.org/10.1007/s41315-018-0060-z

Finch, H., & Lewis, J. (2003). Qualitative research practice: A guide for social science students and researchers. Sage Publications.

Flink, N., Veltheim, T., & Featherstone, A. (2024). Experiences in Transitioning from Traditional to More Effective Human Machine Interface Concepts at Pulp and Paper Mills. Pulp & Beyond.

Ghosh, B. (2018). Methodology of Research in Sociology. INFLIBNET Centre. Retrieved from *https://ebooks.inflibnet.ac.in/socp3/*

Groves, R. M., Fowler, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). Survey Methodology. John Wiley & Sons.

Harris, L., & Brown, G. T. L. (2010). Mixing interview and questionnaire methods: Practical problems in aligning data. *Practical Assessment, Research & Evaluation, 15*(1). *http://pareonline.net/pdf/v15n1.pdf*

Hollifield et al. (2008). High performance HMI handbook, a comprehensive guide to designing, implementing and maintaining effective HMIs for industrial plant operations.

International Organization for Standardization. (2011). Graphical symbols — Safety colours and safety signs, Part 1: Design principles for safety signs and safety markings ISO 3864-1:2011. *https://www.iso.org/standard/51021.html*

International Organization for Standardization. (2019). Ergonomics of human-system interaction. ISO 9241-210:2019. ISO. *https://www.iso.org/standard/77520.html*

Johnson, R. B., & Turner, L. A. (2003). Data collection strategies in mixed methods research. In A. Tashakkori & C. Teddlie (Eds.), Handbook of Mixed Methods in Social & Behavioral Research (pp. 297-319). Sage Publications.

Kitzinger, J. (1994). The methodology of focus groups: The importance of interaction between research participants. Sociology of Health & Illness, 16(1), 103-121.

Liamputtong, P. (2011). Focus group methodology and principles. In Focus Group Methodology: Principles and Practice (pp. 31-49). SAGE Publications Ltd, *https://doi.org/10.4135/9781473957657*

Lowdermilk, Travis. User-Centered Design. 1st edition. Sebastopol, Calif: O'Reilly, 2013. Print.

Machinary Safety of Safety Components | OMRON Industrial Automation. (2024). Omron.com. https://www.ia.omron.com/

Montalbano, Joe, and Brad Lehman. Human-Centered Agile : A Unified Approach for Better Outcomes. New York, NY: Routledge, 2024. Print.

Morgan, D. L. (1997). Introduction. In Focus Groups as Qualitative Research (Second Edition ed., pp. 2-7). SAGE Publications, Inc., *https://doi.org/10.4135/9781412984287*

Nielsen, J. (1994, April 24). 10 Usability Heuristics for User Interface Design. Nielsen Norman Group. *https://www.nngroup.com/articles/ten-usability-heuristics/*

Nielsen, J. (1994a). Enhancing the explanatory power of usability heuristics. Proc. ACM CHI'94 Conf. (Boston, MA, April 24-28), 152-158.

Nielsen, J., & Chan, M. (2024, January 26). Mental Models. Nielsen Norman Group. *https://www.nngroup.com/articles/mental-models/*

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. International Journal of Qualitative Methods, 16(1), 1-13.

Oishi, S. M. (2003). How to design an interview for in-person administration. In How to Conduct In-Person Interviews for Surveys (2 ed., pp. 21-58). SAGE Publications, Inc., *https://doi.org/10.4135/9781412984416*

Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) (Text with EEA relevance). (2016). Official Journal, L 119, 1-88. ELI: *http://data.europa.eu/eli/reg/2016/679/oj[legislation*]

Rosala, M. (2022, August 17). How to Analyze Qualitative Data from UX Research: Thematic Analysis. Nielsen Norman Group. *https://www.nngroup.com/articles/thematic-analysis/*

Stouffer, K., Stouffer, K., Zimmerman, T., Tang, C., Cichonski, J., Pease, M., ... & Downard, W. (2019). Cybersecurity Framework Manufacturing Profile Low Impact Level Example Implementations Guide: Volume 2 Process-based Manufacturing System Use Case. US Department of Commerce, National Institute of Standards and Technology.

Uusitalo, A. (2022). *Design guidelines for process components* [Internal company document]. Valmet.

APPENDIX 1: SURVEY

Safety components in Valmet's automation

Welcome to our survey! Your valuable input will contribute to our ongoing thesis research aimed at enhancing the User Experience (UX) and design of safety components in automation systems.

Objective:
We are interested in your existing knowledge of safety components. Specifically, we want to determine if users can distinguish safety components from normal components and gather insights to improve the design to ensure clear differentiation.

No Wrong Answers:
Please remember that there are no wrong answers in this survey. It is not a test of your knowledge but an opportunity for you to share your thoughts and experiences.

Your Participation Matters:
Your expertise and insights are crucial to this research, as they will help shape the future of safety component interfaces. Whether you are an operator, technician, engineer, or manager, your perspective is invaluable.

Confidentiality:
Rest assured, your responses will only be used for the thesis and won't be shared with any third party, and your personal information will remain anonymous.

1

Can you differentiate between a normal component and a safety component in Valmet UI

- Yes
- No

Figure 24 *Survey - page 1*

2

Looking at the appearance, can you differentiate between safety component and a normal component? Choose the normal component.

vaihtoehto yksi   vaihtoehto kakski

- ◯ Option 1
- ◯ Option 2

3

Can you select the safety components from the following options?

vaihtoehto yksi   vaihtoehto kaksi

- ◯ Option 1
- ◯ Option 2
- ◯ Both are normal components
- ◯ Both are safety components

Figure 25 *Survey - page 2*

4

What do you think makes a safety component different from a normal component?

5

When you think of a safety component, what colour do you think of?

- [ ] Yellow
- [ ] Red
- [ ] Orange
- [ ] Grey

6

Which one of the following do you think is a safety component?

vaihtoehto yksi   vaihtoehto kaksi

- ○ Option A
- ○ Option B
- ○ Both A and B

Figure 26 *Survey - Page 3*

7

Which one of the following is indicating the safety interlocking

vaihtoehto yksi   vaihtoehto kaksi

- ☐ Option 1
- ☐ Option 2
- ☐ Other

8

How would you interpret the following situation

- ◯ Both are safety components that are in alarming state
- ◯ Emergency button is pressed hence motor has stopped because of the safety interlocking
- ◯ Emergency button is pressed and motor is alarming. Both situations are unrelated
- ◯ Other

Figure 27 *Survey - page 4*

APPENDIX 2: SURVEY RESULTS

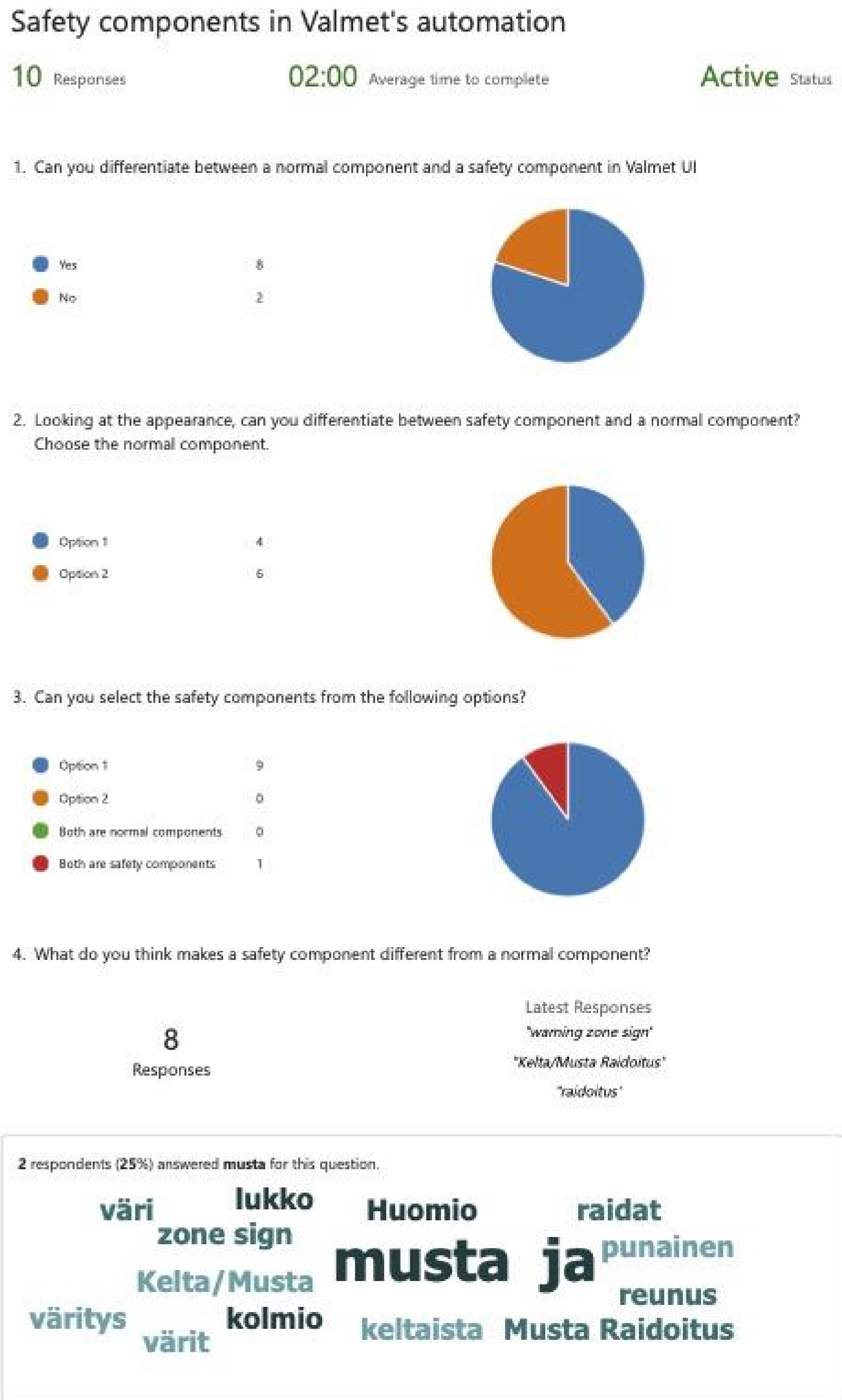

Figure 28 *Survey results 1*

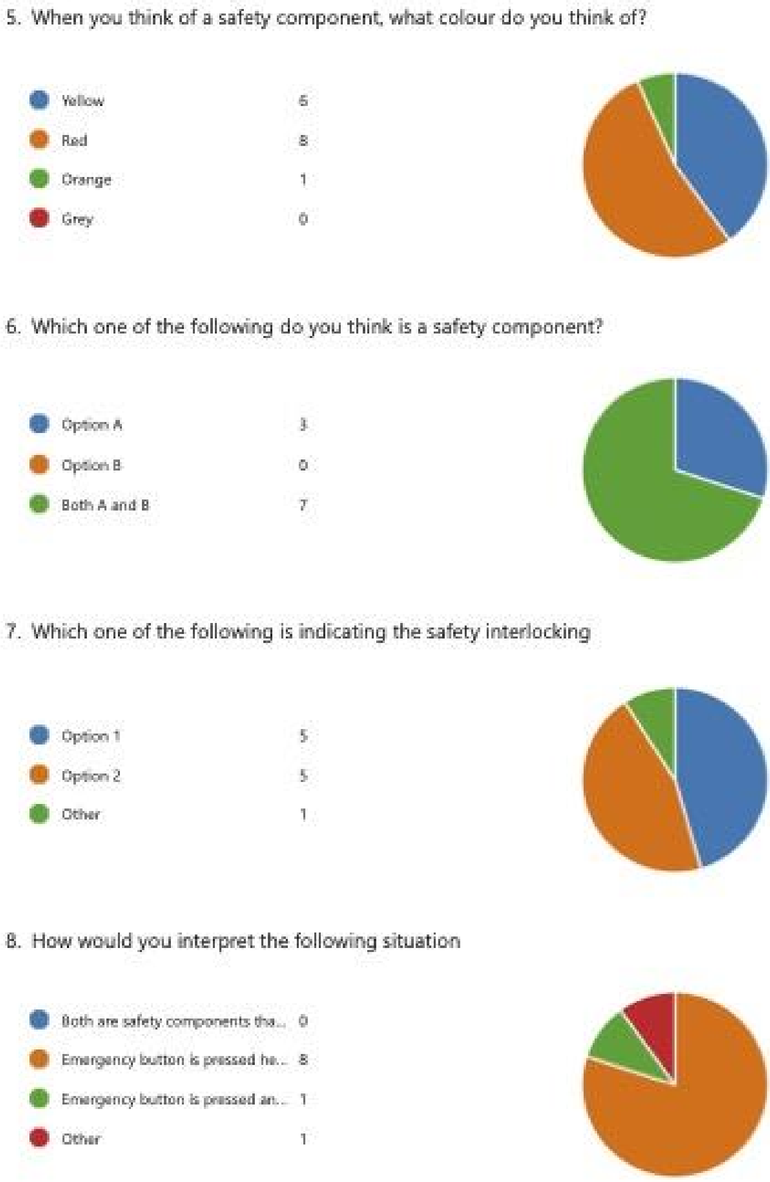

Figure 29 *Survey results 2*