Optimising Welding Machine HMIs

A Human-Centred Design Approach to Usability and Facilitation of Automated Welding Machines

Master's thesis in Interaction Design and Technologies (MPIDE)

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Abstract

As welding systems become more automated and intelligent, the Human-Machine Interfaces (HMI) become crucial for utilising the advantages such systems aim to achieve. This thesis explores what modern user interface design principles should be considered when designing the Human-machine interface (HMI) of industrial welding machines. A pre-study involving interviews, observations, and operator feedback provided insights into Submerged Arc Welding (SAW), Industry 4.0, and intelligent welding systems (IWS). The project then underwent four iterations of design and evaluation, including problem definition, ideation, prototyping, user testing, and analysis. Using a human-centred design approach, key findings highlighted the importance of customisation, intuitive navigation, clear communication, appropriate permission levels, and reducing cognitive load. These insights informed specific design guidelines to improve HMI usability. Our results confirm that a human-centred approach effectively addressed the research question and project aim. However, the guidelines need further validation through extensive user testing and real-world application. In conclusion, this thesis demonstrates that user feedback leads to more user-friendly and efficient HMI designs, supporting the transition to automated and intelligent welding systems. Future work should focus on validating these guidelines to solidify their industry application.

Keywords: Human Machine Interface, Design Guidelines, Welding Machine, Automation, User Experience, Usability, Human-Centred Design, Interaction Design, Prototyping

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Louise Lind, Gothenburg, May 2024

Gustaf Lundberg, Gothenburg, May 2024

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1. Introduction

Interaction design is a critical component of user experience design, focusing on creating interfaces that facilitate efficient interactions between users and technology (Cooper, A., et al., 2014, pp 167-179). Over the years, welding machines have evolved remarkably, becoming increasingly described as intelligent welding systems. According to Wang et al. (2020), intelligent welding systems leverage modern technologies to mimic, enhance, and sometimes replace human operators in tasks such as sensing, learning, decision-making, monitoring, and control. The transition from manual to automated and subsequently to intelligent systems has underscored the importance of customization and adaptability in welding processes. Initially, welding processes were a fully manual process requiring substantial human intervention to maintain efficiency and consistency. However, advancements in automation and robotics have gradually replaced many manual tasks, necessitating extensive pre-programming and control (Wang et al., 2020). Despite reducing manual labour, these pre-programmed paths often lack the flexibility to adapt to dynamic and real-time changes during the welding process. Consequently, the role of operators has shifted from direct interaction to supervisory roles, demanding new methods of communication and control of these systems.

Wang et al. (2020) emphasise that modern interaction design should enable operators to seamlessly modify tasks in response to environmental changes, thereby improving flexibility and efficiency. With the increasing automation of systems, it is crucial to revisit the operator's input and interaction with these systems. As Cooper et al. (2014, pp 167-179) describe, interaction design should streamline workflows, minimise user errors, and ensure that features are easily accessible.

A stakeholder company within the welding machine manufacturing industry faces such challenges, with a new product that needs to facilitate easy access to essential features, as the shift from manual- to automated welding will directly impact welders' user experience. The future vision for this thesis, the stakeholder and their welding machines includes full automation, supported by sensors and cameras attached to the hardware and an intuitive Human-Machine Interface (HMI). Currently, the welding system does not support fully automated operations but can execute automated processes once the operator provides all necessary parameters and settings. This shift demands new requirements, workflows, and views for the HMI, a process that the stakeholder is currently undergoing. The philosophy behind the current HMI is to build on users' familiarity with previous HMIs used on other products, making incremental changes to maintain consistency and align with the stakeholder's vision. At this stage of the project, it is crucial that the HMI accurately represents the functions of the welding system, even though resources for more extensive user insights are on hold for the time being.

Through the application of design principles, interviews, and user tests, the aim is to establish design guidelines that not only enhance user-friendliness but also allow less experienced operators to learn quickly, reducing training time and uncertainty.

1.2 Problem Statement

The main stakeholder of the thesis project currently has a semi-automated welding system that is in continuous development to become fully automated. Developing an HMI that can function in a semi-automated process as well as a fully automated process is a complex objective. The authors acknowledge the current state of the machine as semi-automated but certain design decisions must cater for a fully automated process for the future development. A crucial element for a functioning semi-automated welder is the HMIs capabilities to communicate to operators the essential information, provide all necessary functions while also catering for an easy to navigate interface. To use the strengths automated processes could provide, it is needed to create trust for the operators towards the machine, this is where the HMI plays a critical role. As Ekman et al. (2018) describe trust in automated systems is influenced by three key phases: pre-use, during use, and post-use. In each of these phases, the Human-Machine Interface (HMI) plays a crucial role in influencing the users' experiences and creating trust.

However, as Wang et al. (2020) highlights, the increasing intelligence and automation of welding systems lead to more complexity, with more parameters and settings than ever before. This complexity poses a real challenge for designers, as they must account for a vast array of variables while ensuring the system remains user-friendly and trustworthy. Thus, while it is essential to build trust through thoughtful HMI design across all phases of interaction, navigating the intricate nature of advanced automated systems complicates this task.

Considering the potential for enhancements, efforts are underway to develop a user-friendly interface that enhances efficiency. With this goal in mind, an evaluation and design proposal for the HMI is being conducted. This process emphasises the significance of interaction design principles and explores how their implementation can enhance usability and safety.

1.3 Research Question and Aim

Q: What modern user interface design principles should be considered when designing the Human-machine interface (HMI) of industrial welding machines?

The aim with this thesis is to evaluate the current state of interaction design in the stakeholders welding machines. It will also identify the usability and challenges in the existing HMI of the welding machines through conducting interviews with experienced operators as well as informants with industry knowledge. Lastly, develop mock-ups that draw from the insights and considerations acquired during the initial interviews to conduct user testing. From this, design guidelines, viable solutions and overall recommendations will be communicated to the stakeholders to support their goal in creating the desired user experience and facilitate future automatization. This also involves evaluating how current welding tool interfaces can benefit from being remodelled with the user experience in mind. This is through looking at views, symbols and use cases to be able to research what certain needs and criteria are present for an HMI and translate it towards a user focused design.

1.4 Research Area

Despite advancements in technology, human operators remain essential in industrial work. According to Villani et al. (2019), evolving trends in production and management have led to shifts in employment conditions and requirements. Initially tasked with manually operating machines through the full process, operators now primarily oversee and monitor processes, prepared to intervene in case of machine faults or production changes (Villani et al., 2019). This transition not only displaces lower-skilled labour, but also demands a higher skill level for monitoring and managing advanced automation systems, thus HMIs have emerged as pivotal elements within this dynamic, serving as the link between operators and machines (Villani et al., 2019).

The research area for this thesis encompasses the domain of welding machines, with a particular focus on the importance of interaction design in improving usability, safety, and overall user experience of their HMIs. Interaction design is an essential element within the realm of user experience design, focusing on creating interfaces that facilitate efficient interactions between users and their machines. This thesis aims to identify and address areas for improvement in the usability and learnability of HMIs to enhance the overall user experience for operators. To ensure the proposed solutions are viable, credible, and reliable, several iterations of mock-ups have been developed, aligning with stakeholder visions and established design principles. This approach has occasionally resulted in design recommendations that diverge from traditional norms in interaction and graphical interface design. User testing has also been employed to evaluate the impact of these choices on achieving the final HMI objectives and guidelines.

The research began with initial interviews, discussions, and analyses, leading to the identification of two primary areas for further investigation and development within the current HMI framework. First, the study examines whether the interface can be made user-friendly enough for novice users to perform specific tasks effectively. Second, it evaluates the effect of utilising a more human-centred design approach to enhance the ease of use of the HMI.

Informed decisions regarding the hierarchy and navigational structure are proposed to improve the user experience. This focus on strategic design aims to ensure that enhancements to the HMI are both functionally and ergonomically sound, and that the proposed design guidelines align with human-centred design principles.

2. Background & Related Research

According to Krupitzer et al. (2020) there is a question whether manufacturing is currently subject to a new disruptive revolution, commonly referred to as Industry 4.0. Industry 4.0 is described by Krupitzer et al. (2020) as a shift in the industry where humans now rely on intelligent, inter-connected cyber-physical production systems and machines which is the main controller for the process flow of the industrial production. The authors further argue that machines which involve a considerable number of decisions autonomously set new requirements for the interaction between human and machine (Krupitzer et al., 2020). The shift that is Industry 4.0, is seen as a transformative force in advanced economies and in today's globalised business landscape, and that maintaining competitiveness is crucial for all industries, as failure to do so can lead to loss of market share and viability (Müller et al., 2018). While Krupitzer et al. (2020) describes challenges such as high labour costs compared to emerging economies, Müller et al. (2018) finds that advanced automation presents an opportunity to enhance productivity and mitigate cost disadvantages, and that implementing advanced automation solutions in companies can potentially improve productivity and reduce reliance on labour-intensive operations, thereby enhancing competitiveness in the market. Lastly, Krupitzer et al. (2020) claims that industry 4.0 initiatives are the integration of human operators into advanced production processes, emphasising human-centred automation in manufacturing. As such, the authors of this thesis surmise that while there is no definite agreement in literature of what implications Industry 4.0 will have, it would benefit from integration of both human and machine capabilities to enhance the overall manufacturing process.

2.1 Stakeholder and the Welding Machine

The main stakeholder involved with this thesis is a welding machine manufacturer, are a Swedish based company, and has been operating since the early 1900s. While they provide a variety of different tools for different use cases, ranging from small hand operated equipment to fifteen metres tall welding machines, the focus in this thesis was on their machines for industrial use. Another stakeholder in this thesis were the operators who are operating the manufacturers' welding machines and will be a large knowledge source when it comes to gaining insights in the machine's capabilities and the operators' user requirements. There were also relevance of hearing from other individuals within the stakeholder company to understand their users' requirements and how their machines are viewed upon and used in a daily setting. To establish an understanding of the welding machine examined in this thesis, Table 1 details the main operational tasks of the hardware components that constitutes the machine.

Table 1:Welding machine components

Welding Machine Components

Hardware Components	Operations & Tasks
Camera/Sensor	Continuously monitor temperature and weld joint alignment, providing real-time data to ensure precision and quality. Enable immediate adjustments to the welding operation, such as modifying speed or torch position, based on detected anomalies.
Power Source	The power source supplies the necessary energy to create the weld, ensuring consistent and stable arc performance. It adjusts the current and voltage in real-time according to set parameters to match the welding parameters, maintaining optimal weld quality and efficiency.
Welding Head	The welding head precisely directs the welding torch and electrode to the weld seam. It ensures accurate placement and consistent movement, adapting to real-time adjustments for optimal weld quality and consistency.
Carriage	The carriage ensures precise and consistent movement of the welding equipment, allowing for a semi-automated welding process. It can be equipped with motorised controls to move along rails or tracks, enabling accurate positioning and steady welding speeds
Axis	The axes are typically defined as X (horizontal), Y (vertical), and Z (depth). The number of axes determines the machine's flexibility and precision, enabling it to perform intricate welds on complex geometries by adjusting the position and orientation of the welding torch relative to the work-piece.
Boom	The boom is a structural component that supports and extends the reach of the welding head or torch. It allows for vertical and horizontal movement, providing flexibility to access different parts of a large work-piece or multiple welding stations. The boom is typically mounted on a stable base or carriage
Flux	A granular material that is spread over the welding area to shield the weld from atmospheric contamination. During the welding process, the flux melts and forms a protective slag and gas shield around the weld pool, preventing oxidation and other impurities. The flux also helps to stabilize the arc and improve the weld's mechanical properties.
Welding Wire	Welding wire a continuous, solid wire that is fed automatically into the welding arc beneath a layer of granular flux. The wire conducts the electric current that generates the heat required for welding and serves as filler material, contributing to the formation of the weld bead. The composition of the welding wire is chosen based on the base metals being welded and the desired mechanical properties of the finished weld.

2.2 The Role of Welders/Operators

For this thesis, the authors adopted the classification system used by the stakeholder company to categorise employees based on their experience levels and job tasks related to the machines. The term "operator," as used throughout this thesis, refers to employees directly involved with the operation of the welding machine. Before the implementation of the automated system, operators were responsible for manually completing the entire welding process. This included setting up the system, ensuring all necessary materials such as flux and welding wire were loaded (see Table 1), and maintaining proper system functionality. During the welding process, operators manually adjusted and steered the welding head to fill the joint. With the introduction of the automated system, the role of the operator has shifted to a supervisory capacity. While operators still handle pre-welding tasks, they now oversee the automated process to ensure the machine operates correctly. This shift has allowed operators to manage multiple welding machines simultaneously, altering the requirements for the HMI as use cases evolve.

The second role related to the operation of welding machines is that of welding engineers. According to informants at the stakeholder company, the primary responsibility of welding engineers is to ensure that the welding machines provided to the customers function properly. Engineers are tasked with the initial installation of the machines at designated locations, requiring a high level of technical expertise and knowledge of all parameters and settings to ensure the machine meets the specific needs of the customer. Additionally, welding engineers visit customers to address any issues that arise with the machines. As the welding machines become more automated, the engineers working tasks remain similar to as before. However, since operators are not actively involved during the welding process, the engineers have increased responsibility in making sure that welding machines functions properly.

The distinction between these two roles and their interaction with the HMI of the welding machine lies in their use of different parameters. Operators focus on parameters to ensure the welding process runs smoothly, while engineers engage with parameters that configure the machine to perform the desired welding process as specified by the operators.

Requirements for working with Industrial Welding Machines

The requirements for working with industrial welding machines can vary depending on country or job title, but it is common for welders to obtain an IW (International Welder) certification, which is an internationally recognised certification in over 30 countries, enabling welders to advance their knowledge and professional opportunities in the industry (utbildning.se, n.d.). With this certification, the welder can work with more complex tasks such as orbital welding or work as a robot welding operator (utbildning.se, n.d.). In Sweden, organisations and schools offering IW training are approved by the Swedish Welding commission. The training consists of 18 modules with three levels of training for different welding methods, and concludes with theoretical and practical exams (utbildning.se, n.d.). While the stakeholder company has not provided specifics for the experience required for operating the welding machine examined in this thesis it was found, through examining job openings from the stakeholder, that the common requirement is a welding related degree as well as between 2-4 years of related experience.

2.3 Submerged Arc Welding (SAW)

Another key aspect is the kind of welding that the stakeholder machine facilitates, which is Submerged Arc Welding (SAW). According to Houldcroft (1990) SAW is a versatile and well-established welding technique, particularly noted for its proficiency in joining thicker steel materials, while also applicable for swiftly automating the welding process of smaller parts. Further, Houldcroft (1990) details a variety of advantages of SAW, including reliability, consistently high-quality welds, and the ability to generate seamless welding contours, much due to its utilisation of welding flux, a granular substance which is strategically placed over the welding arc which conceals both the arc itself and the molten metal pool beneath it.

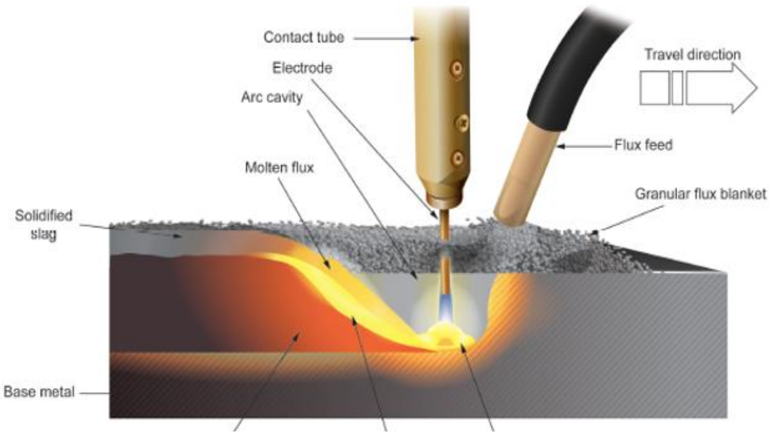

Figure 1: Schematic diagram of submerged arc (Pates, n.d. What is submerged arc welding (SAW), CWB Group

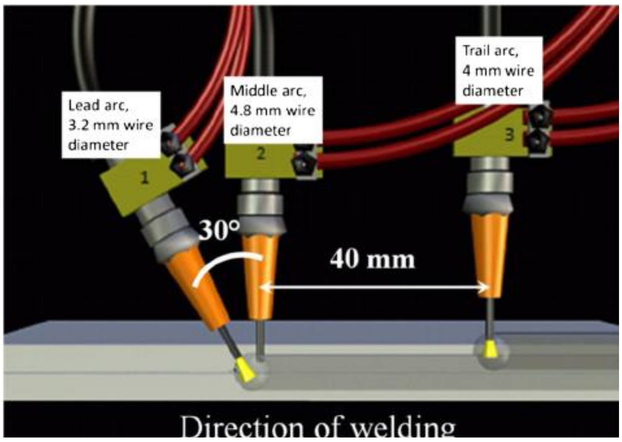

Figure 2:Arrangement of three welding arcs in the welding setup (Layus et.al.,2014)

The SAW technique serves multiple purposes: it eliminates harmful radiation, mitigates the risk of flashes and glare, and minimises the emission of smoke and fumes during the welding process (Houldcroft, 1990). In SAW welding one or several welding arcs, or welding heads can be used (Figure 2).

2.4 Towards Intelligent Welding Systems

According to Wang et al. (2020) an intelligent welding system (IWS) is an advanced system whose goal is to reach a high level of productivity, flexibility, quality and functional and operational precision while also being cost efficient. These systems are designed around welding automation or unmanned welding, robots, and flexibility. By applying intelligent technologies such as artificial intelligence (AI), the systems aim to replace and/or enhance human sensory capabilities. These welding systems might completely replace operators, but humans and machines may also cooperate to perform different welding processes.

It is important to distinguish IWS from other similar definitions. As Wang et al. (2020) describes, the definition of a welding system is not merely based on the degree of automation, it is more about optimization, autonomy, and the ability to adapt to changing environmental aspects of welding. The researchers of the article "*Intelligent welding system technologies: State-of-the-art review and Perspectives"* (2020) argues that robotic welding for example is not intelligent welding, instead it is an important enabler for IWS. Intelligent welding is much more than that, it is an entire ecosystem that consists of humans, operators, and designers.

To apply a correct definition for this thesis an extensive understanding of the stakeholder's system had to be gathered and compared to existing definitions. While the stakeholder's product includes the technologies described by Wang et al. (2020) as enablers for an IWS, such as sensors, sensing techniques, signal processing, feature extraction, and vision-signal processing, the system currently does not support the parameter-signal processing, modelling and simulation, decision-Making and Artificial intelligence, and machine learning. While the stakeholders have never claimed to provide a IWS and/or are conservative with contributing with information for an ongoing development project for the thesis authors, a clear definition has not been set or yet communicated.

For this thesis, two definitions defined by Wang et al. (2020) encapsulates the core capabilities of the stakeholders welding system. Firstly, “Robot welding” is defined as “Robot welding is the use of mechanised programmable tools (robots), which completely automate a welding process by both performing the welding and handling the part.” (Wang et al., 2020, p.377).

The current state of the machine is that it can completely automate a welding process by performing the actual welding and handling the different parts, but has capabilities that transcend this definition, leading to the next definition applicable being “Virtual welding” with the following definition “This system uses a welding robot to carry the torch and sensors to perform the welding and measure the weld pool surface. The human welder holds a virtual torch whose operation is like a real torch such that his operation and adjustment are still natural and free in 3D space.” (Wang et al., 2020, p.377). The stakeholders welding machine can measure the weld joint surface to predict the applicable welding operation but for this to be done, manual input of parameters, actions, and later finalised decisions is made by the human operator. While no definition described by Wang et al. (2020) is fully applicable to the system at hand, the authors for this thesis decide to define the system as partially robotic and more specifically a semi-automated robotic system, since it encapsulates the view of a robotic welding system similarly to how this thesis have approached design suggestions and guidelines presented in the results. While defining the system as semi-automated robotic system, in the view of its capabilities, it will be referred as a semi-automated system throughout this thesis.

2.4.1 Technological Advancements in Welding

The welding industry continues to develop, where various technological advancements that aims to improve the efficiency and quality of welding processes appear. One innovation is the development of an augmented reality (AR) helmet designed to enhance the manual welding process. According to Hillers et al. (2004), this AR helmet utilises a stereoscopic high dynamic range (HDR) complementary metal-oxide-semiconductor (CMOS) camera system, which provides welders with improved visibility by displaying real-time guidance and critical information directly within the helmet's visor. This technology aims to reduce cognitive workload and improve precision, leading to improved welding operations. Initial tests have shown promising results, with welders reporting improved accuracy and ease of use (Hillers et al., 2004).

Further advancing the integration of AR in welding, Papakostas et al. (2022) explore the use of AR welding simulators in engineering training. Their study shows the efficiency, safety, and cost-effectiveness of AR simulators, which reduce the need for consumables and infrastructure while minimising physical risks and harmful emissions associated with traditional welding training. By incorporating perceived enjoyment and system quality into the Technology Acceptance Model (TAM), they demonstrate that these factors significantly influence users' perceived usefulness and ease of use, thereby enhancing user acceptance. The AR simulators provide a realistic and engaging training environment, improving the practical orientation and quality of learning for trainees. This approach helps new welders learn efficiently and prepare for real-world applications. The findings suggest that AR technology, through both helmets and simulators, holds significant potential to revolutionize welding by improving precision, safety, and user engagement (Papakostas et al., 2022). This integration of AR technology in welding underscores the potential for advanced interfaces to significantly impact the industry, aligning with our research focus on enhancing Human-Machine Interfaces (HMI) for automated welding systems.

3.Theory

The following chapters will present concepts in theory that are related to the purpose of this thesis. While there is much theory that can be applied in the realm of interaction design, some delimitations have been made to keep the scope of this thesis.

3.1 Human-Computer Interaction and Human-Machine Interaction

Previous research in the field of interaction design for industrial tools such as welding equipment highlights the significance of intuitive interfaces in enhancing user efficiency, safety, and learning (Stephanidis, 2001). When discussing Human Machine Interaction, shortened to HMI in literature, it will be instead referred to HMIN in this thesis to differentiate to the previously presented term; Human-Machine Interface (HMI) to avoid confusion. Both Human-computer interaction (HCI), and Human-Machine Interaction (HMIN) have common requirements according to literature (Ardanza et al., 2019; Stephanidis, 2001).

While the emphasis is often put on the product itself to achieve this, the capability of the HMIN is of key importance. Wölfel et al. (2013) exemplifies this through the relation between products and experiences, referencing a pyramid model (Figure 3) reminiscent of Maslow's Hierarchy of Needs (Wölfel et al., 2013, referred in Maslow, 1943). This model, when applied to industrial design, highlights the necessity for products to fulfil not only basic functional, reliable, and usable criteria, but also to embody convenience, pleasure, and meaning for users.

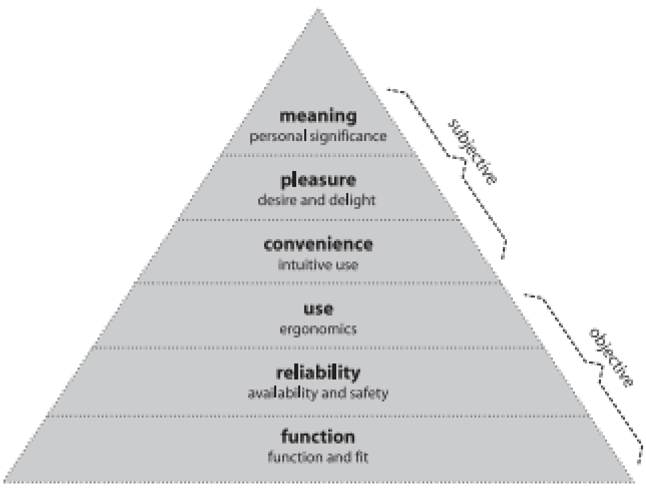

Figure 3: Model of user experience in industrial design (Wölfel, C. et.al., 2013)

This can be related to the principles of HCI, which are crucial for designing interfaces that optimise the interaction between users and the welding machines. As defined by Stephanidis. (2001), HCI has the aim to ensure that interactive, computer-based systems take safety, utility, effectiveness, efficiency, accessibility, and usability into account. To do this, a system needs to be evaluated after such requirements, and be understood in the context of when a user interacts with it.

According to Ardanza et al. (2019), achieving optimal productivity hinges on striking a delicate balance between HMIN devices and software solutions. They further state that seamlessly integrating innovative HMIs with the right software, entire production plants can witness remarkable efficiency improvements. Further Industry 4.0 underscores the pivotal role of operators within the new industrial landscape. The overarching goal is to empower operators with customised, adaptable machines that facilitate access to essential production information directly from their workstations (Ardanza et al., 2019). This access is facilitated through the installation of HMIs on production lines and manufacturing machinery. The evolution of industrial HMIs is marked by a transition from rudimentary LCD displays to a diverse array of products. Modern offerings include state-of-the-art large touch displays boasting high resolutions and wireless functionalities (Ardanza et al., 2019). To better understand the functionality for such an HMI, Ardanza et al. (2019: p.4046) has made the following requirements:

- Monitoring and visualisation of real-time process data.
- Supervision, which allows to adjust the working conditions of the process directly from the HMI.
- Alarms management to recognise malfunctions or misbehaviour during the manufacturing process.
- Control the process to keep certain variables within safety limits.
- Store and review recent activity, providing accessing methods to retrieve the recent data and metadata of the manufacturing process.

For the development of the mock-up HMI for this thesis, these requirements are crucial to ensure it follows such functionality standards. While HMIN and HCI are two different kinds of interactions between technology and humans, the above literature has some commonality in terms of requirements, and so while such concepts are not always interchangeable or specifically applicable for the entirety of this thesis, it provides some insight to how such literature can be applied to develop the HMI.

3.2 Human-Centred Design, User Centred Design, and Human Factors

Campese et.al. (2020), defines Human Centred Design as;

> An approach for user involvement comprising principles that guide establishment of goals and the accomplishment of activities, enabling user information & knowledge to be obtained and incorporated in the design process, using methods and techniques identified in the body of knowledge of this area. (Campese et al., 2020, p.37)

This definition by Campese et al. (2020) comes from an analysis of the terms Human-Centred Design (HCD) and User-Centred Design (UCD) in academic literature to clarify their importance in design fields and aims to foster communication and theoretical development in the field. Their findings indicated that many authors perceive UCD and HCD as synonymous. However, Campese et al. (2020) proposed that HCD is a broader concept than UCD, as it encompasses a wider range of stakeholders beyond just the end-users. They recommended the use of the term HCD based on several observations: an increase in its usage in academic publications, its prevalence in standards, and its preference in general internet searches, as demonstrated in their research. As such, the concept HCD in this thesis will be used both when discussing concepts mentioned as HCD and UCD from literature.

Khamaisi et al. (2021) sees HCD as an iterative design process that involves placing users at the centre of the design process. To meet the demands for high-quality standards, production flexibility, and innovation, there is a growing emphasis on HCD approaches. These approaches prioritise human factors (HF), which encompass various environmental, organisational, and work-related elements, as well as individual human characteristics that can significantly impact health and safety when interacting with technology. HCD aims to integrate HF into the design process, focusing on making interactive systems more user-friendly by leveraging human factors and ergonomics knowledge, and usability techniques. By embracing HCD principles, new methodologies emerge for defining requirements and recommendations to effectively design complex systems with a user-oriented approach.

Similarly, Nguyen Ngoc et al. (2022) found through a systematic literature review that there exists a predominant focus on technical aspects rather than addressing issues concerning error-prone interactions between human and non-human actors. They argue that while usability remains a crucial metric for evaluating the adequacy of HMI designs, there is a growing recognition of the importance of the user's multidimensional experience, encompassing emotional and psychological responses. This broader concept of HCD prioritises the user's needs and involvement in the collaborative development process to enhance acceptability and adoption. HCD places the user at the forefront, aiming to optimise user satisfaction and acceptance.

3.2.1 Participatory Design

The article "Automotive HMI design and participatory user involvement: review and perspectives" by François et al. (2017) explores the integration of participatory design in automotive human-machine interface (HMI) development, emphasising the importance of user involvement throughout the design process. The benefits of participatory design, where users are actively involved in the design process, not just as subjects in usability testing but as co-designers. This approach is shown to enhance the design evaluation by directly integrating user feedback and preferences into the development process, potentially leading to more user-centred and effective HMI solutions François et al. (2017).

3.2.2 Human-Centred Design in Intelligent Manufacturing Systems (IMS)

Research conducted by Trentesaux and Millot (2016) points out that researchers often fail to care for strengths and weaknesses that human operators possess when designing industrial control systems. Instead, there is often a techno-centred approach which often leads to only taking human operators into considerations towards the final stages of the design process. This approach is problematic according to Trentesaux and Millot (2016) since it suggests that human operators will only be there to correct any unexpected situations. In an event of unexpected situations will have to be managed efficiently, humans therefore must be as Trentesaux and Millot (2016) describes them “magic humans” referencing to humans need to be simultaneously coordinated, efficient and rapid. Which according to Pacauz-Lemoine et al.

(2017) suggests that adapting the techno-centred approach leads to an overestimation of the human operator's capabilities. Who would need to behave perfectly when needed and within a predetermined appropriate response time and perform the precisely correct actions in the face of unexpected situations.

Because of this development of disregarding humans in the design process of IMS, Pacauz-Lemoine et al. (2017) conducted a study on the development of IMS, whereas Wang et al. (2020) description of IWS falls under the category of IMS. Pacauz-Lemoine et al. (2017) highlights that as the evolution of industrial processes continues from manual interactions towards fully automated systems, the importance of effective human-machine cooperation to manage and optimise these systems increases. As a correlation of increasingly autonomous operations the humans often become more unaware of the operations. To counter this situation Pacauz-Lemoine et al. (2017) advocate for a human-centred design approach, which would ensure that operators are, despite automation, actively involved in the process. This approach would involve the integration of human factors from the initial stages of system design. Experiments conducted show indications that the human-centred approach improves system performance and acceptability among human operators, also supported by Krupitzer et al. (2020). It is also essential to develop an IMS which is effective, reactive, and resilient, ultimately leading to improved interactions and cooperation between operators and intelligent systems (Pacauz-Lemoine et al., 2017).

3.3 Usability Engineering

Incorporating usability engineering principles ensures that the HMI is intuitive, efficient, and easy to learn, and involves applying principles, methods, and guidelines to design interfaces that meet users' needs and preferences (Carroll & Rosson., 2014).

Key concepts and considerations include identifying the tasks that users need to perform with the welding machines and designing the interface to support these tasks effectively. This can be done by performing a contextual inquiry. Carroll and Rosson (2014) defines contextual inquiry as when the observer is located near the workstation where the subject is engaging with the task to be evaluated. The observer watches and takes notes but should also ask questions when certain interactions of interest occur, to reveal pressure points or distinguish unexpected interactions that could be relevant to the design of the HMI. Another consideration is involving users in the evaluation of interface designs through usability testing sessions, such as interviews. Carroll and Rosson (2014) recommends semi-structured interviews for this, as it ensures the questions of importance are answered while leaving space to pursue interesting comments or topics outside of them. Lastly, a heuristic evaluation can facilitate uncovering usability problems early in the design process. These rules or best practices can either come from industry standards, or practitioners. Carroll and Rosson (2014) argues that experts use heuristics and guidelines to analyse the software interface, where they examine aspects like language, layout, navigation, and visual design. Lastly, they perform a usability inspection, which is a formal evaluation process where usability experts systematically review the software interface against a set of tasks. The outcome of the evaluation is a report detailing identified usability issues. These problems may be categorised by severity or cost to fix, helping the design team prioritise improvements.

3.4 Safety Engineering

Leveson (2002) states that System safety should be treated as an integral component of systems engineering.

> Accidents result from a lack of appropriate constraints on system design. The role of the system engineer or system safety engineer is to identify the design constraints necessary to maintain safety and to ensure that the system design, including the social and organisational aspects of the system and not just the physical ones, enforce them. (Leveson, 2002, p. 59)

Thus, integrating safety engineering concepts helps in designing interfaces that mitigate risks and promote safe operations (Saleh et al., 2014), such as identifying potential dangers associated with the use of the welding machines and assessing the likelihood and degree of associated risks (Leveson, 2002). While this cannot be fully applicable to this thesis due to it being conducted without an in-depth understanding of the industry, some considerations are necessary to design an interface that does not contradict safety engineering concepts. As such, it is important to ensure that the interface design complies with relevant safety standards and regulations provided by the stakeholder.

3.5 Mental Models

Carroll and Olson (1988) define a mental model as the following;

> Knowledge of how the system works, what its components are, how they are related, what the internal processes are, and how they affect the components. It is this conceptualization that allows the user not only to construct actions for novel tasks but also to explain why a particular action produces the results it does. (Carroll & Olson, 1988, p. 47)

In the context of interface design for welding machines, designing interfaces that align with users' mental models of the welding process and tool operation is crucial for usability and effectiveness. Thus, Carroll and Olson (1988) argue that if the interface reflects an appropriate model, the user can learn it with less guidance and perform fewer errors. However, Mohamed et al. (2017) sees how the main challenge in designing for usability and security is to cautiously strike a balance between protecting the system from unauthorised disclosure and cognitively design the system to conform to the user's expectations and satisfaction. The consideration of mental models in a user interface can play a key role in minimising risks and improving the manipulation of embedded controls and unforeseen security practices of novice users. Assessing the user's mental model for the design phase is critical for the design success, and usability designers must assess the mental model of the potential users and their behaviour when they plan to design a new system. These insights can be used to improve a user's cognition and expectations, which will directly improve system usability (Mohamed et al., 2017).

3.6 Design Guidelines

In a survey paper by Villani et al. (2018), they review human-robot collaboration in industrial settings, with a specific focus on both physical and cognitive interactions. While the paper by Villani et al. (2018) focuses on interaction between operator and non-confined robots, called "Cobots", some of the identified challenges and opportunities found can be applied to industry tools such as automated welding machines. Villani et al. (2018) found that through Industry 4.0, there is an emerging trend of using collaborative robotic solutions to support automation. Villani et al. (2018) identifies that there exists a complexity of how operators are expected to interact with the robots in a reduced time, and thus hinges on intuitive interfaces, while minimising the risk for user error. A solution provided by Villani et al. (2018) is to apply human-centred design principles to the human-robot interfaces, where considerations such as information processing decision-making and more are taken into the design. As referenced in the survey paper by Villani et al. (2018), a paper by Opto22 (2014;2021) makes some recommendations when developing HMIs for automated systems;

1. *Put data in context to increase the operator's situation awareness.*

This recommendation highlights the importance of situational awareness when interacting with HMIs. This means aligning the operator's mental model with the system's interface presentation. To do this, Opto22 (2014;2021) recommends collaborating with operators to understand their mental models and their responsibilities. Further, Opto22 (2014;2021) states the importance of highlighting critical information and letting less important data be in the background. To therefore understand the operators' actual tasks are crucial for effective HMI design.

2. *Make it easy by reducing the operator's cognitive load.*

Opto22 (2014;2021) defines cognitive load as the amount of mental effort required to understand information. As complex commands increase the cognitive load, and familiar commands or icons decrease it. They therefore recommend prioritising the perspective of the operators by engaging directly with operators to understand their tasks and needs, rather than asking for direct suggestions for how to improve the HMI. They also recommend observation of the operator's work to gain insights into such tasks and potential needs.

3. *Build an information hierarchy that is easily navigated.*

The last recommendation is to logically group information to help streamline the monitoring tasks, as in having the operator check individual screens to track statues, grouping them together on one screen allows for better simultaneous monitoring.

Opto22 (2014;2021) outlines several methods for grouping; physical proximity, similar shapes, sizes, colours, enclosing boxes, or connective lines, as this enhances the perceptions of connections as well as decluttering the screen. They also state that an effective HMI should prioritise simplicity and clarity by eliminating unnecessary visual elements, e.g. colour gradients, 3D depictions or backgrounds. A last recommendation is to promote consistency in the HMI design, as it can foster the confidence of the operator and facilitates a faster understanding and response process during abnormal situations, allowing the operator to navigate between screens quickly without wasting time on unnecessary clicks.

Di Gregorio et al. (2020) recommends similar design guidelines, focusing on supporting monitoring industrial production for Andon interfaces. In Industry 4.0 as there is an increased complexity when it comes to data processing, as well as a need for operators to understand such data quickly to avoid critical situations (Di Gregorio et al., 2020). This paper will present the relevant guidelines, excluding those that are not applicable.

By examining existing industrial interfaces, their first design guideline is for monitoring the state of the machine as there is a risk to overload the interface. For this problem, they recommend using distinguishable colours for each state if the readability of information is kept (Figure 4). They also recommend an icon to indicate specifics of the state (Di Gregorio et al., 2020).

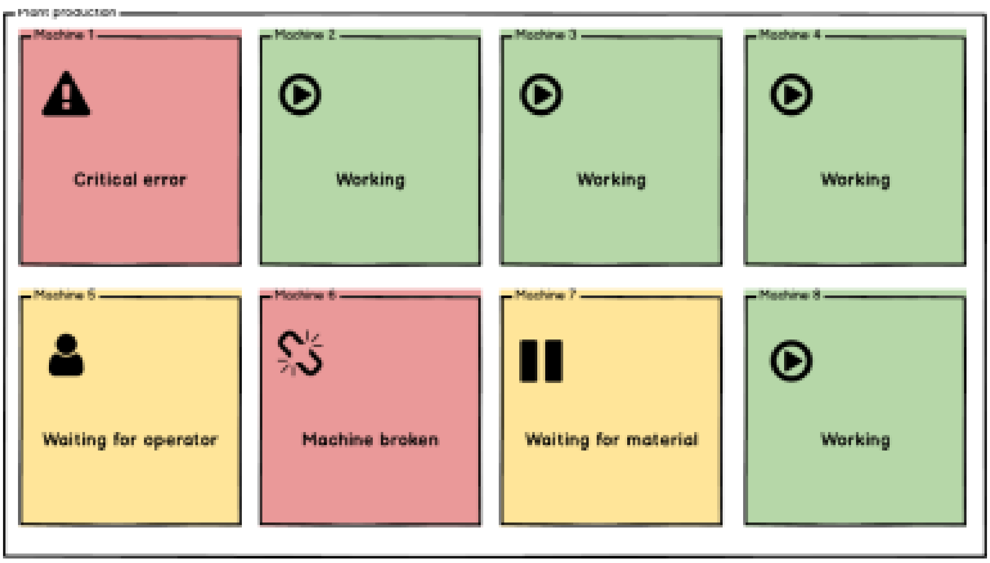

Figure 4: Icon utilisation to indicate specifics of the state (Di Gregorio et al., 2020)

Their fourth design guideline stems from the issue of monitoring the Overall Equipment Effectiveness (OEE) in a single display (Di Gregorio et al., 2020). Here, they recommend separating each machine using separating graphics, such as cards, where each card contains information and elements for that specific machine (Di Gregorio et al., 2020). With these guidelines, amongst others, their main view for the Andon interface can be seen in Figure 5.

Figure 5: Andon interface separating graphics (Di Gregorio et.al., 2020)

3.6.1 Colour, Contrast, and Visual Aesthetics

When designing user interfaces, it is important to consider all the visual elements, such as colours, contrast, element sizes and placement. When it comes to colour, Watzman and Re (2007) presents some general guidelines for how to apply colour in design. First, it is important to use colour coding, a scheme that reinforces the hierarchy of information. The colours should also “work with the project identity or established visual language” (Watzman & Re, 2007, pp. 347-348). Watzman and Re (2007) also puts emphasis on contrast, which is the range between dark and light colours. Whatever choice of colour, the contrast of what is to be read and its background needs to be easily differentiated. Watzman and Re (2007) also claims that this is especially important for digital displays, as the designer has a smaller level of control of the output that will be used for the design. Another dimension is the overarching concept of visual aesthetics. Gonzalez et al. (2019) argues that research within HCI has primarily focused on how effective and efficient the interaction is, but that user satisfaction is often also dependent on how visually aesthetic the interface is. Further, Gonzalez et al. (2019) recognises that designing for brand experience that enforces visual recognition is a relatively new topic within HCI, and thus requires the creation of new processes and tools that ensures the tangibility of the brand. With this in mind, there are some limitations as to what design principles can be applied to this thesis, apart from broader, general design principles found under interaction design, as there is a lack of domain specific research when it comes to colour, contrast and visual aesthetics in HMI design.

When it comes to icons, Shen et al. (2023) performed a study to explore the effects of icons in in-vehicle HMIs on drivers' cognitive performance, by evaluating how the icon formats, concreteness and familiarity of it affected it. The authors note that processing the information of a graphical element such as icon is not only to locate them, but to understand the icons meaning in the current context (Shen et al., 2023). Concrete icons are those that depict objects that are related to knowledge stemming from everyday life or experiences, and Shen et al. (2023) claims that previous studies used in their paper shows that people have an increased performance in recognising such icons, as they are more closely related to reality. They are also more helpful for new users that can be unfamiliar with graphic information, and thus textual information can therefore be added to clarify the functional meaning. However, Shen et al. (2023) notes that too much textual information can decrease the level of recognition, and so keywords can be utilised instead.

4. Methodology

The research was planned to employ a mixed-methods approach, combining qualitative and quantitative techniques to achieve a comprehensive understanding of the usability and safety issues in the current HMI design and to evaluate the effectiveness of proposed design solutions. Following chapter contains description of methods and meta-methods that were relevant for this thesis.

4.1 Double Diamond

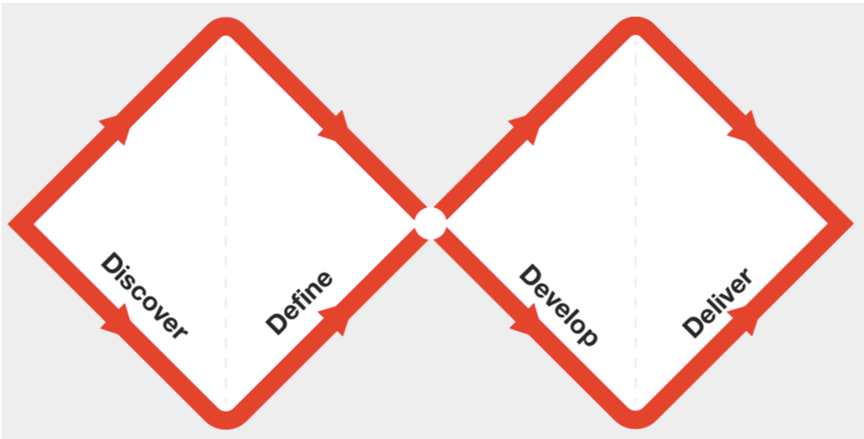

Figure 6: An illustration of the Double Diamond (The Design Council. n.d.)

The Double Diamond design process, developed by the Design Council in 2005, stands as a methodology that emerged from an evaluation of design practices among eleven global brands. This method, structured to graphically show the design process, through four stages: Discover, Define, Develop, and Deliver. These stages are crafted to take an idea to the final product or service delivery. The Double Diamond model is great for adaptability, urging users to tailor it to align with each individual project. Each stage is designed to include iterative cycles that facilitate ongoing exploration and testing, highlighting the model's adaptability across different projects (Gustafsson, 2019, referencing Design Council, 2007). The phases are defined for this thesis as followed in the subsequent chapters.

4.1.1 Discover

The Discover phase of the Double Diamond process is important for identifying ideas, with broad exploration and minimal formalisation to spark innovation. This initial stage is marked by uncertainty but plays a significant role in defining the project's direction. The quality of work during Discover significantly impacts the project's innovative outcomes. (Gustafsson, 2019, referencing Frishammar & Florén, 2010; Eschberger, 2018; Rhea, 2003).

4.1.2 Define

The Define phase is the second stage of the Double Diamond process which refines initial ideas into defined end goals, aligning them with objectives. This stage is important for evaluating the viability of concepts. Various methods and management tools are used to define approaches and make pivotal decisions, setting the stage for the following development phases (Gustafsson, 2019, referencing Design Council, 2007).

4.1.3 Develop

The Develop phase, the third stage of the Double Diamond process, focuses on developing, iterating, and evaluating the product. This stage involves using methods like brainstorming, prototyping, and testing to refine the concept into a product. Visual management tools are important for tracking progress and facilitating communication. This phase is crucial for identifying and rectifying potential flaws, with a strong emphasis on prototyping to visualise and evaluate concepts before moving to implementation (Gustafsson, 2019, referencing Design Council, 2007; Frishammar & Florén, 2010).

4.1.4 Deliver

The Deliver phase is the final stage of the Double Diamond process, where the idea does its final testing, production, and launch. This phase emphasises evaluation to ensure the product or service meets its objectives. The launch process often involves collaboration with different teams to ensure consistency across all platforms. Feedback is important at this stage, serving both as validation for the design team and as a source of insights for future product development (Gustafsson, 2019, referencing Design Council, 2007).

4.2 Agile Management Methods

In the following section a couple of well-established and commonly used agile methods will be presented. Agile methodology is an iterative approach to project management that emphasises collaboration and feedback. According to Highsmith (2009), Agile project management focuses on creating innovation by encouraging adaptive planning, evolutionary development, early delivery, and continuous improvement (Highsmith, 2009).

4.2.1 Scrum Methodology

In the book "Business Object Design and Implementation" (1997) Schwaber discusses the Scrum methodology. Scrum is a popular framework in agile project management and is characterised by a combination of defined and empirical processes designed to improve flexibility and adaptability in project development. Scrum starts off with a Planning phase and ends with a Closure phase. Schwaber (1997) continues to describe that the central characterization of Scrum are the Sprint phases. Each Sprint iteration is closely monitored with controls, such as risk management strategies, to ensure flexibility is maximised. The scrum framework during this phase is open to environmental influences until the Closure phase. Throughout the Planning and Sprint phases, the project and its direction can be changed in response to external factors such as competitive pressures, time variables, quality standards, and financial considerations. This flexibility allows the project to adapt and evolve in real-time to information and environmental contexts, making sure that the final deliverable is optimally aligned with the project's objectives and external conditions (Schwaber, 1997).

4.2.2 Waterfall Methodology

Waterfall Methodology being one of the first defined system development processes, it adopts a linear approach where each phase follows the other in a sequential manner. This method creates a predictable development process. Its biggest limitation is its rigidity, the waterfall method does not accommodate unexpected outputs from any phase, often leading to challenges if deviations from the plan occur (Schwaber, 1997).

4.2.3 Spiral Methodology

Barry Boehm (1988) identified problems with the Waterfall model and developed the Spiral methodology. It incorporates elements of the Waterfall approach but enhances flexibility through the integration of risk assessment and prototyping at the end of each phase, addressing the previous limitation waterfall method had in terms of its rigidity. This method allows for iterative refinement, steadily working through the layers of development, with opportunities to adjust the project's direction based on prototype evaluations. Despite being an iterative approach, each phase within the Spiral methodology still follows a similar linear sequence as the Waterfall model, containing defined processes, requiring careful management to ensure alignment with overall project goals (Schwaber, 1997).

Amongst the previously mentioned project management methods, additional tools can be used to facilitate a clear structure for project management, such as a Gantt chart. The Gantt chart, developed in the early twentieth century is a well-established tool for such purposes (Geraldi & Lechter, 2012). As time management is often a large factor of how to plan a project, the Gantt chart can help organise the planned activities in a clearly visualised period and could be a beneficial addition to the above agile methods.

4.4 Data Gathering Methods

In the following chapters, relevant data gathering methods will be presented to position the thesis of how data has been collected.

4.4.1 Selection Group & Sampling

Convenience sapling is presented by Etikan et al. (2016) as a kind of non-random sampling, using informants that meet a certain criterion such as availability, ease of access, geographical proximity and/or willingness to participate. As such, convenience sampling is a more affordable and easy method for gathering data, but Etikan et al. (2016) emphasises that it should be noted by the researcher that convenience sampling would differ from randomly selected participants, and that convenience sampling is likely to be bias, which is also described by Lopez and Whitehead (2013) who recognises that convenience sampling can suffer from either under-representation or over-representation of a particular group, which can limit the researcher in both validity and reliability. Another similar sampling method is purposive sampling, which Lopez and Whitehead (2013, p.7) describes when the informants "have the required status or experience or are known to possess special knowledge to provide the information researchers seek". This is a method which combines well with qualitative research, as there are no formal criteria for the sample size, rather that the data is rich enough.

Lopez and Whitehead (2013) therefore views sampling and data collection as directly related, where the data collected from the sample can either be direct, such as a recording, or indirect, such as interactions, and that whatever can be observed or communicated are considered to be potential or actual data.

4.4.2 Literature Review

Denney and Tewksbury (2013) define a literature review as:

> A comprehensive overview of prior research regarding a specific topic. The overview both shows the reader what is known about a topic, and what is not yet known, thereby setting up the rationale or need for a new investigation, which is what the actual study to which the literature review is attached seeks to do. (Denney & Tewksbury, 2013, p. 216)

Denney and Tewksbury (2013) emphasise the importance of doing a literature review in research, as it helps the writer summarise and integrate earlier research of the topic, which both demonstrates the writer's understanding of the available information but can help the writer’s own learning process. Further, it creates credibility to the author and can more easily identify weaknesses in the found literature (Denney & Tewksbury, 2013). When it comes to qualitative research, Denney and Tewksbury (2013) recommends having a literature review that has a more inclusive approach to the research topic.

As an example “if the research question is how alcohol abuse influences the tendency to commit violent crime, then it would be necessary to include the general theme of substance abuse and how it influences committing all forms of crime” (Denney & Tewksbury, 2013, p.222). As to what sources to use, Denney and Tewksbury (2013) names academic journal articles and academic books to be the most appropriate, but to also consider the date of publishing, as it indicates that the most updated research has been used, avoiding the risks of referring to research problems that might have been resolved in newer literature (Denney & Tewksbury, 2013).

4.4.3 Interviews

According to Lopez and Whitehead (2013), interviews are seen as the key method for qualitative data collection. Patel and Davidson (2019) believe that qualitative interviews generate nuanced descriptions of general phenomena in the informants' everyday working lives. Furthermore, Patel and Davidson (2019) suggest that qualitative interviews are meant to have open-ended questions as it is difficult to formulate answer alternatives in advance. Therefore, a semi-structured interview method can be used, where there is a certain structure in the questions to find key findings out of the informant’s answers and keep the session within the scope of the subject, but there is flexibility to adapt the questions based on the informant's answers (Lopez & Whitehead, 2013; Patel & Davidson 2019). This is important as informants might veer into subjects outside of the predetermined questions, which can provide important insights that would otherwise not have been discovered (Lopez & Whitehead, 2013). This is to gather information about the informants' perceived work situation. Bell (2015) recommends that one or more pilot interviews be conducted. There will be a pilot interview conducted with an informant that had no knowledge about the project but had the technical knowledge and operating experience to give us some sort of responses on our questions and structure.

It is important according to Patel and Davidson (2019) to motivate the informants, this can be done through an introduction to inform to what they will contribute. According to Patel and Davidson (2019) humans speak not only with the mouth but with body language as well and any sign of a negative body language can make the informant go into a defensive posture.
By recording the interview, the writers of the thesis can fully focus on the informant as Bell (2015) recommend. Recording the interview may also hinder the informant from answering in an honest manner (Bell, 2015).

4.4.4 User Testing

User testing and heuristic evaluation methods can offer valuable insights into usability issues in both fully developed interfaces and those in the iterative design phase (Tan et al., 2009). User testing depends on users' experiences and feedback, typically conducted in a scenario-based environment. As such, user testing tends to evaluate the existing state of the interface, where heuristic evaluation usually covers structural problems, or root causes of problems. (Tan et al., 2009). As an example, if the scenario in the user test does not contain the possibility to fail, the user test cannot answer whether the user would fail outside of the predefined scenario (Tan et al., 2009). Therefore, Tan et al. (2009) recommends utilising both user testing and heuristic analysis for the most optimal results, however at various stages. heuristic analysis should be implemented at initial stages of the development process, while user testing should be conducted at a later stage of the development process, as later stages in the design usually means there are more details and may need a scenario-based approach.

4.5 Thematic Analysis Method

Thematic analysis being a qualitative research method to aid researchers to identify, analyse and report patterns or themes within data. It is an approach that involves a systematic process of coding and theme development. Useful for researchers when making sense of collective or shared meanings and experiences (Castleberry & Nolen, 2018). According to Clarke and Braun (2017) the first step of a thematic analysis is to systematically search for codes, small but important aspects that later are used to build comprehensive themes.

Thematic analysis offers several strengths which makes it a valuable method in qualitative research. The first is its nature of being flexible and adaptable to a wide variety of research questions, data types and across different disciplines for various purposes (Castleberry & Nolen, 2018; Nowell et al., 2017). Continuing when used correctly thematic analysis allows researchers to delve deeply into the data, by capturing the complexity of meanings, experiences and social phenomena which might be overlooked or missed in quantitative methods (Castleberry & Nolen, 2018). Castleberry and Nolen (2018) describe thematic analysis as an accessible method for researchers to adapt. In its relatively straightforward nature, it is easy to learn. Describing it as an excellent method for researchers new to qualitative methods, without compromising the depth of analysis. Allowing even novice researchers to conduct meaningful and insightful studies.

If researchers were to present to people from both academic and non-academic audiences, thematic analysis facilitates a clear communication. By structuring data from themes is easily understandable, enhancing the impact and reach of the research. Thematic analysis also compliments other research methods well. It can be used alongside both qualitative and quantitative approaches, which enhances the robustness and comprehensiveness of research findings (Castleberry & Nolen, 2018; Nowell et al., 2017).

Castleberry and Nolen (2018) discuss some shortcomings of the method despite being a flexible and broad use. First, with the open-ended nature that qualitative data is, it can make it difficult to identify patterns compared to numerical data. With such complexity it requires careful and transparent methodological practices to ensure credibility. Moreover, the authors describe that there is a misconception that qualitative analysis software can perform the analysis independently. The authors argue for the researchers' skills to interpret data as paramount for thematic analysis. A common issue with the methodology is the potential for researcher bias in the coding process, since thematic analysis does not provide a standardised guidebook, requiring researchers to adapt their approach to specific context and data which can be demanding and time-consuming (Castleberry & Nolen, 2018). A major drawback according to Nowell (2017) is the limited amount of substantial literature on the method compared to other methods, suggesting that grounded theory, ethnography, and phenomenology are more tested theories. Which in turn can leave novice researchers using thematic analysis to feel unsure of how to conduct a rigorous analysis. Nowell (2017) also points out the aspect about language. Since thematic analysis does not allow researchers to make claims about language use in the same way that other qualitative methods do.

4.6 Trust towards Autonomous Systems

In the article "Creating Appropriate Trust in Automated Vehicle Systems: A Framework for HMI Design" by Ekman et al. (2018), they research how HMI design can influence trust towards automated vehicle systems. The authors present a framework that integrates trust-affecting factors into HMI design to foster an appropriate level of trust in automated driving (AD) systems. The study identifies that trust is incredibly important for user acceptance and proper use of AD systems, emphasising that an HMI can influence trust even before users first interact with a system. The proposed framework categorises the phases of user interaction into pre-use, during use, and post-use, with a focus on how each phase can affect trust levels. The framework is designed to be flexible, serving as a guideline for HMI designers rather than a strict protocol Ekman et al. (2018).

4.7 Wicked Problems

Tom Ritchey explores the concept of wicked problems in the article "Modelling Social Messes with Morphological Analysis," a concept first introduced by Rittel and Webber in 1973. Wicked problems are identified by their complex, ambiguous nature, and their resistance to traditional straightforward analytical solutions (Ritchey, 2013).

Building on this, the article “Wicked Problems Revisited” by Coyne (2005) delves deeper into the nature of wicked problems within the design field. That these design challenges are also deeply intertwined with human practices, values, and social constructs. Coyne highlights the limitations of traditional rational problem-solving methods, advocating for a broader, more inclusive rationality to effectively address the wickedness inherent in design tasks. Wicked problems are not anomalies but are standard within design, necessitating that designers embrace uncertainty, maintain ongoing dialogues, and adopt reflective and adaptive problem-solving strategies (Coyne, 2005).

Both Ritchey (2013) and Coyne (2005) highlight the critical need for new methodologies and philosophical insights in tackling the complex, interconnected challenges presented by wicked problems in social and design contexts. Their works underscore a shift towards more integrative, responsive, and flexible approaches in planning and problem-solving to address the nuanced realities of contemporary societal issues.

As both Ritchey (2013) and Coyne (2005) highlights, wicked problems are bound to appear in most types of projects, especially common in design projects. Methods and frameworks to identify and tackle these projects will be a crucial part of this thesis.

4.7.1 General Morphological Analysis (GMA)

General Morphological Analysis (GMA) qualitative technique that enables analysis of complex problem fields that cannot be addressed by traditional quantitative methods. It was developed by Fritz Zwicky in the mid-20th century for astronomical research and has since been adapted across a wide array of disciplines for strategic planning and policy analysis (Ritchey, 2011). The historical development of GMA emphasises its wide applicability and roots in diverse fields including the classification of astrophysical objects, rocket propulsion systems, and even the legal aspects of space travel (Ritchey, 2003). This background highlights the method's versatility and potential in handling various complex scenarios.

The approach begins with the identification of variables relevant to the problem at hand and their possible states. These variables are arranged in a multi-dimensional configuration space. Cross-consistency assessment (CCA) is then conducted to eliminate logically incompatible combinations of these conditions, which refines the space to feasible configurations that form a solution space (Ritchey, 2013). GMA is particularly noted for its capacity to handle "wicked problems" that are indeterminate and have no clear solution paths. Its strength lies in its ability to open new perspectives and uncover solutions that are not immediately apparent through traditional linear thinking (Ritchey, 2011; Ritchey, 2013). Modern implementations of GMA leverage computer-aided tools to manage the complexity and extend the capabilities of this method. These tools support the iterative process of analysis and synthesis inherent in GMA, allowing for more dynamic and flexible model manipulation (Ritchey, 2006). GMA provides an "audit trail" that improves traceability and reproducibility, addressing a common critique of qualitative methods regarding their lack of transparency (Ritchey, 2003).

Given its inherent capabilities, General Morphological Analysis (GMA) is well-suited to address challenges such as wicked problems, which are highly probable to arise though this thesis.

4.8 Validity and Reliability

Information on how to achieve and ensure validity and reliability should be included in the method description (Patel & Davidsson, 2019; Bell, 2015). There are many factors that can affect the results of a study, such as emotions or sudden events.

Reliability is a measure of the extent to which a certain methodology would give the same result on distant occasions in otherwise similar circumstances (Bell, 2015). Reliability has tried to be conducted by having the same person interviewing all the informants, and by always having all informants on the same site for the interview. Bias is a concept that Bell (2015) mentions and is described as a skew in the result because those who interview can influence the informants in the interview, which has been avoided in this project.

Validity is about a particular question describing what it wants to describe, or if there is a vague definition that can leave more questions (Bell, 2015). When it comes to data gathering through interviews, Alshenqeeti (2014) recommends a few techniques that can maintain reliability and validity when interviewing, such as not asking leading questions and giving the informant space and time to sum up and clarify their responses.

4.9 Formative Evaluation

Formative evaluation is an established evaluation method in the field of design research. It is purposely developed for iterative improvement and refinement. According to Nieveen and Folmer (2013), formative evaluation is well suited to work as a guide in the development process. Through the method continuous feedback is gathered during the development leading to subsequent revisions. This cyclical process of analysis, design, evaluation, and revision is important to the development (Nieveen & Folmer, 2013).

Studies show how the learning has been benefited by incorporating formative evaluation in schools. Which has helped students understand learning objectives and the necessary steps to reach them. This process allows for adaptation of teaching methods to meet individual student needs and fostering a more personalised and effective learning environment. Nieveen and Folmer (2013) states that selecting appropriate formative evaluation methods is important to obtain relevant and accurate data that can guide the iterative development. They continue with highlighting the importance that chosen methods must align with the specific research questions and the stage of development. Which method that is suitable can vary from research to research, but the most important aspect through whichever method is used is the researcher's role. Nieveen and Folmer (2013) highlights their involvement in especially the initial stages of development. Their involvement provides valuable insights and fosters a deeper understanding of the practical challenges and user experiences associated with the prototype. However, it is crucial for researchers to remain objective and mitigate biases that may arise from their attachment to the project.

4.9.1 Screening

This is a method that involves members of the design research team checking the design against a set of predefined criteria. Screening also usually employs a checklist that outlines the required characteristics of the design, to ensure that the basic components and structures of the design meet initial standards. Screening is often used in the initial stages of development when the primary goal is to establish a solid foundation for the intervention (Nieveen and Folmer 2013).

4.9.2 Focus Group

Nieveen and Folmer (2013) explains focus groups as a method that involves gathering a group of informants, often experts or key stakeholders, to react to a prototype of the product. Data collection in this context usually involves organising interviews with the group to gather qualitative feedback. The insights gained from focus groups are particularly useful for understanding the broader context of the design, identifying potential pitfalls, and ensuring that the design aligns with best practices and current knowledge in the field (Nieveen & Folmer 2013).

4.9.3 Walkthrough

A walkthrough is another formative evaluation method where the design research team and representatives of the target group collaboratively review the prototype. This process is like a rehearsal in a theatre play, where participants navigate through the prototype while evaluators use checklists, conduct interviews, and observe the participants. Walkthroughs are especially effective for identifying practical issues and usability concerns, allowing for immediate adjustments to be made based on real-time feedback (Nieveen & Folmer 2013).

4.9.4 Micro-evaluation

Micro-evaluation is a method where a small group of target users are using parts of the product in a controlled environment outside its normal setting. This method employs different data collection methods such as interviews, observations, questionnaires, and performance assessments through tests. Micro-evaluations provide detailed feedback on specific elements of the design, helping to refine these components before broader implementation (Nieveen & Folmer 2013).

4.10 Triangulation

Triangulation and the inclusion of external evaluators in the later stages of the evaluation process are crucial for maintaining the rigour and objectivity of design research. When employing formative evaluation methods, it is critical to select informants who are well suited to answer the research questions. This ensures that the data collected is both relevant and valuable (Nieveen & Folmer, 2013).

To further enhance the reliability and internal validity of the findings, triangulation should be considered. This method involves using multiple data collection techniques, diverse types of informants, various instruments, and conducting data collection at separate times and locations. By leveraging the strengths of diverse methods and compensating for their individual weaknesses, triangulation provides a more comprehensive understanding of how an intervention is perceived and used. For example, combining interviews, observations, and questionnaires can yield a richer and more nuanced perspective (Nieveen & Folmer, 2013).
Thurmond (2001) emphasises that triangulation should be applied thoughtfully, particularly in qualitative research settings. It is important to clearly explain the reasons for using triangulation to highlight its benefits in enhancing the depth and breadth of the research.

4.11 Wizard of Oz

A method to conduct iterative design is presented in the article “Wizard of Oz Support throughout an Iterative Design Process" (Dow et al., 2005) explores the integration of the Wizard of Oz (WOz) technique within the iterative design processes of HCI. This approach involves an unseen operator, which is called the "wizard," who simulates the responses of computer systems that are not fully functional or developed. This simulation enables the testing of user interfaces and interactions as if the system were complete, allowing designers to observe real user reactions and gather valuable data without the upfront investment in full system development. Using the WOz method in iterative design allows for flexibility since the role of the wizard can change. At first the wizard might actively control most aspects of the interaction, simulating both the system’s responses and its intelligence. As the system matures with each iteration, the wizard's role can transition from an active controller to a passive supervisor, where they oversee the system and intervene only when necessary (Dow et al., 2005).

4.12 Prototyping in Figma

In the paper Design prototyping methods: state of the art in strategies, techniques, and guidelines by Camburn et al. (2017), the several benefits of prototyping are presented, listing the objectives of how prototyping can aid design in development. The first objective is refinement, which is described by Camburn et al. (2017, p.3) as “the process of gradually improving a design”. The benefits with refinement of a design are that you can validate user requirements, identify design concerns, reduce errors, identify design changes that enhance performance and more Camburn et al. (2017). Another benefit is the ability to communicate the design and its capabilities to others, as communicating concepts within the design team, and that the physical medium allows observation of user interaction, where Camburn et al. (2017) also recognises this objective to fall under usability testing to explore human factors in design. Camburn et al. (2017) also stress that the main goal of prototyping is to enhance the user experience and performance of the final product, with an emphasis on that iterative prototyping is intricately linked to improvements in meeting challenging requirements. However, they caution that while simplified prototypes or mock-ups are effective for exploring concepts and facilitating communication, they might misrepresent the actual physical principles and capabilities of the final design. Therefore, these prototypes should be evaluated with care to avoid potential misinterpretations.

Figma, a popular cloud-based collaborative design tool, exemplifies the versatility of prototyping tools available today. It is known for its accessibility and comprehensive features, even on its free plan (Staiano, 2022, p. 5). Figma supports brainstorming, wireframing, and the creation of high-fidelity prototypes, (Staiano, 2022, p. 5) especially through utilising “interactions” which can make static frames alter states, visualising how a functional system would react. As such, Figma is a suitable tool for creating prototypes.

5. Planning

This project started a lot later than what was desired. But through furrow planning in regards to hours spent throughout the weeks we had the goal and confidence of completion before summer of 2024. With a total amount of around 120 hours a week together, we were confident to reach our goal. This situation was communicated to the stakeholder company who are aware of our situation. By spending an additional amount of 20 hours a week/ person we hoped to achieve our objective. The weeks in the following time plan are in accordance with the weeks of the year, starting at week 9 of 2024. The planned result aimed to present the current state of interaction design in the industry manufacturer’s welding tools. It was also identified that the usability and challenges in the existing HMI of the welding machines through conducting interviews and visits with operators using them. Lastly, a mock-up of the HMI with these considerations was made for user testing. From this, we were able to propose design guidelines and recommendations to the stakeholders to enhance the user experience and ensure automation of the system from these reported findings.

The thesis also aimed to present whether the current wielding machine interfaces that are following industry standards can benefit from being remodelled with the user experience in mind. This was made possible by looking at views, symbols and use cases to research what certain needs and criteria are present for an HMI and translate it towards a user focused design.

Week 9: 50h	First meeting with the company, outlining needs, goals and collaboration. **Thesis:** Framework, Academic contribution, Research Question/Problem.
Week 10: 50h	**Company**: Redefining objectives, setting up a plan moving forward. **Thesis:** Framework, Academic contribution, Research Question/Problem.
Week 11: 60h	**Company:** Schedule onsite visitation. **Thesis**: writing.
Week 12: 60h	Outlining final project Scope, Goals, Impact
Week 13: 60h	Understanding use cases, functionalities and safety aspects.
Week 14: 60h	Preparing for interviews, visiting users
Week 15: 60h	**Thesis**: Conduct interviews
Week 16: 60h	**Thesis**: Start with the design phase. Using findings from interviews
Week 17: 60h	Design phase (Figma)
Week 18: 60h	Design phase (Figma)
Week 19: 60h	Iteration. Get back to operators and the company with a mock-up of HMI. Testing.
Week 20: 60h	Redesign + Report Writing
Week 21: 60h	Redesign + Report Writing
Week22/23: 50h	Final changes to report and design. Present findings and solutions for Chalmers and the stakeholder.

Total Hours: 800h/person

6. Execution

The following chapter will describe in detail how the utilisation of methods, frameworks and approach described in earlier chapters has been executed up until the final prototype which embodies the final proposed guidelines. The following chapter is divided in accordance with the four different iterations conducted during the project.

6.1 Iteration One

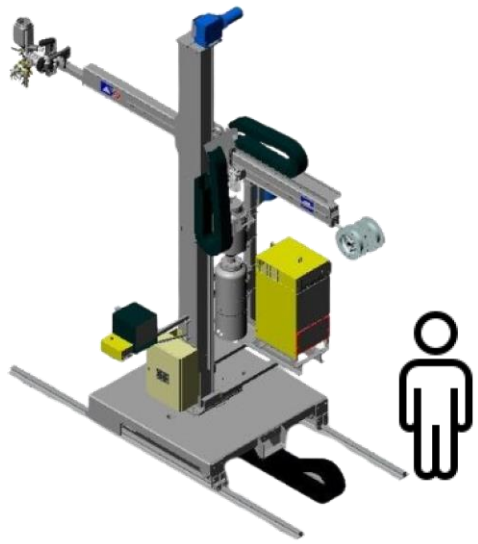

Figure 7:Stakeholder Welding Machine. (Human size reference)

For the first phase of this thesis, there was a need to understand the domain of industry welding, particularly the specific welding machines and domain of the stakeholder. The first meeting with the stakeholder representative introduced the SAW welding process and introduced members of the project for which our findings ultimately will support. After the initial meeting, documents pertaining to the project and other HMIs made by the stakeholder were also provided. Combining these materials with a comprehensive literature review covering HMIs in welding, Industry 4.0, design principles for industrial and automation applications/interfaces laid the groundwork for a thorough understanding of the domain, as well as the formulation of the problem statement and research question.

Another key event in this first phase was the onsite visitation to the stakeholders' facilities a few weeks after the initial meeting. This visit provided us with an opportunity to rise questions, uncertainties or any project related questions gathered from retaining a lot of new information.

Following was a tour of the laboratory and factory where all the hardware development takes place. Such experience was a crucial aspect to gather an overall idea of who the stakeholders are, what they aspire to be and their history. The visit was instrumental in clarifying the operational aspects of welding, the utilisation of tools by the stakeholder and their employees, as well as the spectrum of products in use. Given the stakeholder's approach of incorporating legacy models into their HMI design, understanding older iterations became imperative in designing for the new rendition.

6.1.1 Defining the Problem

The pre-study phase provided a foundational understanding of Submerged Arc Welding (SAW), autonomous welding, Industry 4.0 implications, and the stakeholders' technologies and HMI design. With the new information gathered from learning about this unfamiliar domain, market, and industry, we began to define a problem area for future research that would provide value to both the stakeholder and Chalmers University.

Our understanding of the problem mainly emerged from the cumulative insights gained through conversations, discussions, and observations. This led to the creation of the initial project scope. With assistance from stakeholder representatives and guidance from Chalmers, we formulated the research question presented in the planning report: “What modern user interface design principles should be considered when designing the Human-machine interface (HMI) of industrial welding machines?” Although broad, this research question was appropriate as a starting point within the defined problem area.

The planning report, which was the main deliverable of this phase, proved to be a time-consuming aspect of the thesis. This was primarily due to the extensive effort required to learn the necessary background information, ensuring we were well-prepared to conduct interviews and develop the first iteration of the project. During this period, our agile management approach proved to be highly beneficial. As we developed the planning report, we multitasked across various aspects of the project, including prototyping, conducting literature research, and identifying informants. The agile methodology allowed us to remain flexible and responsive to new information and challenges as they came to light. By breaking the project into manageable sprints and continuously prioritizing tasks, we could efficiently allocate our resources and time.

This iterative process facilitated ongoing adjustments and improvements, ensuring that each phase of the project was informed by the latest findings and insights. The agility of our approach enabled us to maintain momentum and adapt to evolving project requirements effectively.

6.1.2 Development Phase

As previously mentioned, a stakeholder representative responsible for developing the new HMI provided us with a complete walkthrough of their existing prototype. During this session, we had the opportunity to ask questions about functions, symbols, and other uncertainties we had gathered from screenshots we had previously acquired. To support our initial interviews, we recreated this HMI in the software program Figma. Since the representative's prototype was only interactable on their computer, we developed our own version to ensure usability during interviews and user tests. Mock-ups are effective for exploring concepts and facilitating communication, and this mock-up closely mirrored the representative's version and aided the design development (see Figure 9,10 and 11).

There were two main reasons for using a mirrored mock-up. Firstly, we anticipated gathering more valuable insights by allowing informants to provide feedback on a version that took all the system capabilities into account. If we were to create a completely new mock-up from scratch, it would require in-depth understanding of the system and welding machine capabilities, which would have been too time-consuming for the scope of this thesis. Consequently, we did not create an initial sketch for the iteration, as it closely mirrored the representative's mock-up. Secondly, by utilising a mock-up that mirrors the one the stakeholder is currently developing, we can clearly explain and tie back our final design choices and their rationale to their mock-up. This approach will help the stakeholders understand the proposed changes and may ultimately lead to the adoption of some of these improvements in their future designs.

It is important to note that after discussions with the representative, it became clear that there was uncertainty regarding the reasoning behind the layout, functions, and overall design of their mock-up. The prototype had been created quickly for an industry fair, and the representative expressed a need for more operator feedback to understand what worked and what did not. They emphasized that the mock-up was a work in progress and not final.

One key insight from this meeting was the lack of human involvement in the development process, which highlighted the possibility of adopting a human-centred design approach for our project.

6.1.3 Focus Groups

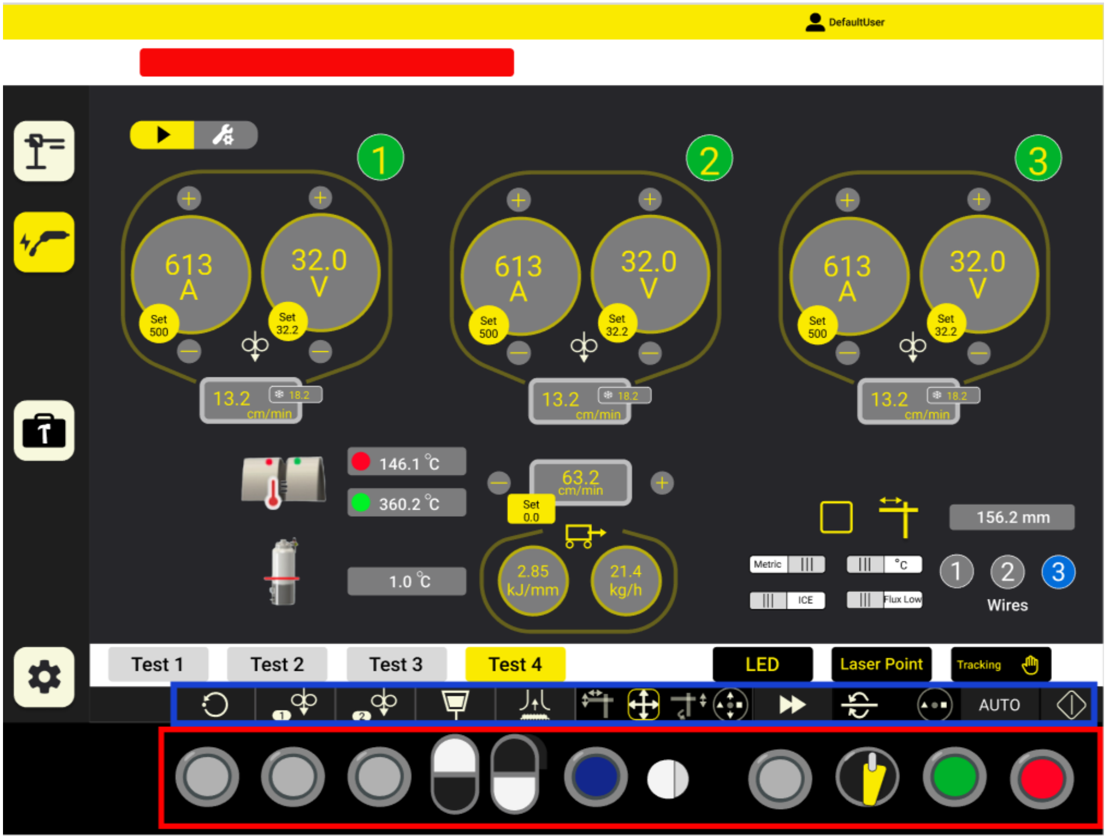

Figure 8: Main Welding View Iteration 1. 1,2 and 4 in the view controls separate welding heads.

As previously mentioned, iteration one would be used during the focus group interviews. In Figure 9, is a view of the first iteration created, which would be used at the initial interviews, consisting of three focus groups. This is the "Main Welding View" as we will reference it throughout the thesis. It is the view visible for the operators when a welding process is active. Through this view operators should have a complete overview of the welding process, and be able to manipulate values in real-time, to adjust to unexpected situations or changes. It is important to note that in Figure 9 the red section at bottom is a visualisation of the hardware buttons incorporated in the screen that will be used for the final HMI. These buttons control the buttons found in the blue section, which are a part of the interface. These can be ignored since they are not a part of the scope for this thesis.

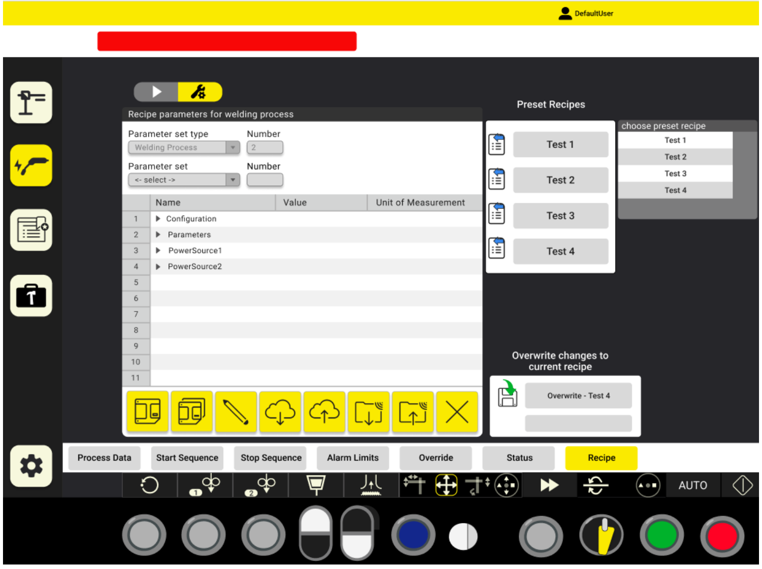

Figure 9: Recipe settings view iteration one.

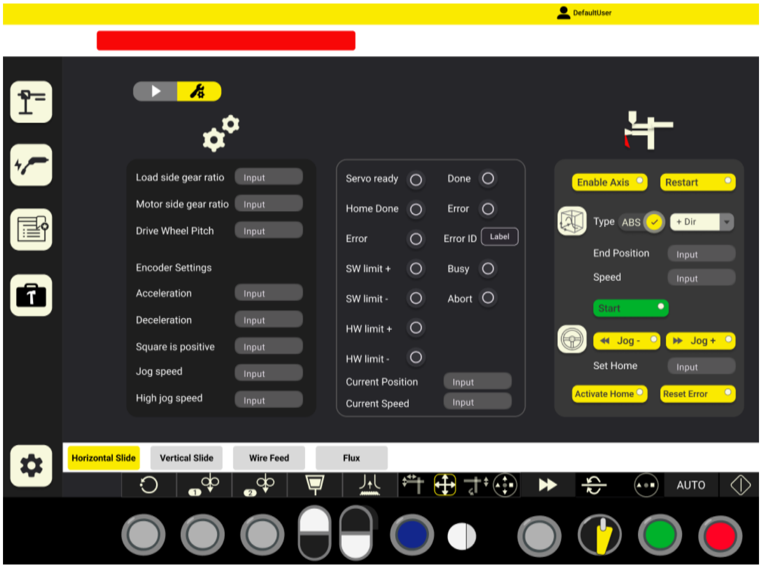

Figure 10: Welding parameters settings view iteration one.

Once iteration one was complete it was time for the second onsite visitation which was spanning over two days. The seven informants available for interviews were employees of the stakeholders, who all possess different amounts of experience in terms of welding and the specific welding machine. Each interview was recorded and spanned for about one hour. The interviews were semi-structured and contained two segments: questions about the current state of the HMI and over-all experience of working with HMIs, and then a presentation of the iteration. During the presentation, the informants were able to freely discuss their impression of the iteration, such as overall architecture, hierarchies of information, symbols, and colours.

Table 2: Interview informants and roles

Interview Informant	Role
Informant 1	Technical Support
Informant 2	Global Service Training on Automation Products
Informant 3	Automation Solutions
Informant 4	Welding Specialist
Informant 5	Service, Research & Development, Automation Solutions
Informant 6	Production Welding and B2C Operations
Informant 7	Production Welding and B2C Operations

The first part of the interview more specifically aimed to provide us with insights to how an operator works day to day with these machines, what is important for them to help them conduct efficient work, and lastly ask questions about their impression of the HMI they currently interact with in their working environment. Also allowing them to suggest functions and design choices that would help them in their work. Through the findings gathered at this stage, the project was able to identify pain points, key aspects, and potential improvements to drive the project forward in line with the scope.

The later part being a presentation of the current iteration had a different angle towards the goal of answering the research question, focusing more on gathering insights that might improve the overall user experience of the final prototype, as well as get feedback on information placements, overwhelming experiences, importance of parameters and information accessible for the operators during different stages of the HMI. This approach allowed for an instant understanding of "dos and don'ts" when continuing with future iterations. These findings might have appeared later if we did not adopt a human-centred approach from the start.

6.1.4 Interviews

Interviews are planned to be conducted on at least seven informants, with different backgrounds and experience of the welding machines, in a manner that matches with Niveen and Folmer (2013) description of a focus group in a formative evaluation approach where a group of stakeholders react to a mock-up of a prototype and provide insights. Niveen and Folmer (2013) continue to highlight the advantage of this method to its capabilities to gather a broader understanding in context of the design, identify problematic behaviours with the design and to ensure that the final design aligns with common practices and knowledge within the field. The possible capabilities Niveen and Folmer (2013) describe focus groups to provide is the reasoning behind the plan to conduct initial interviews in small groups of two-to-three people. These interviews are also planned to be conducted to gather data about which key factors there are for a functioning HMI when operating the welding machines, and with a broad spectrum of informants there has been a broader view of the key factors. The themes for the initial interviews with operators of welding machines:

1. *Underlying and introductory questions.*
2. *Methods and approaches when utilising welding machines.*
3. *Challenges with operating welding machines.*

The underlying and introductory questions are considered due to the informant's working roles, responsibilities with that working role and whether the informant has any previous experience with several types of welding machines from other manufacturers and use cases. Attaining an idea of previous experience is considered when analysing the answers. The second theme is methods and approaches where the informants are asked about what methods and approaches, they have towards operating the welding machines. The third theme will regard challenges with operating the current welding machines, focusing the questions on challenges with technology, interface, safety, and limitations. For the interviews of the operators, the aim will be to do the interview face to face in their working area. The reason for this decision is to make the informants feel more comfortable which in the end might increase the chance of more nuanced responses and a freer dialogue (Patel & Davidson, 2019). To ensure reliable data, one person will hold the interview, while the other will observe, listen, and take notes, and be able to add questions that the interview holder might overlook while being involved in a conversation. All interviews plan to start off with an introduction of the study. It is important in the beginning of the interview to provide an explanation of what the study is for and how they will contribute to the research. The informant will also be informed that they will remain anonymous and only their job title and experience will be noted in the study. Another aspect of the interviews will be to be mindful of behaviour and body language, such as gestures that might come across as negative. This will be possible by having the informants give their approval of being recorded before the interview starts. By recording the interview, the writers of the thesis can fully focus on the informant as Bell (2015) recommend. Recording the interview may also hinder the informant from answering in an honest manner (Bell, 2015). To avoid having the informant answering falsely because of this the informant was promised that the recorded material would be the basis of the result and the recording would be deleted after transcription.

6.1.5 Stakeholder Documentation and Information

Considering the thesis is at a stakeholder company, there is a lot of information that is presented through internal pictures, files, statistics, registers, documents etc. Patel and Davidson (2019) describe how to use documents as a technique for gathering data. This technique fits information that is written down in several diverse ways. With documents, questions about actual conditions and events can be answered. It is important that the presentation of the data is consistent with reality. The documents will mainly be used in the project to gather basic knowledge about the current state of HMI for welding machines and their use cases. The documents that will be provided have been given by members of staff and informants from the stakeholder. Utilising stakeholders' documents could result in a bias carried through the thesis project, which is a concept that Bell (2015) mentions and is described as a skew in the result because those who interview can influence the informants in the interview.

6.1.6 Project Management Utilising Gantt Chart

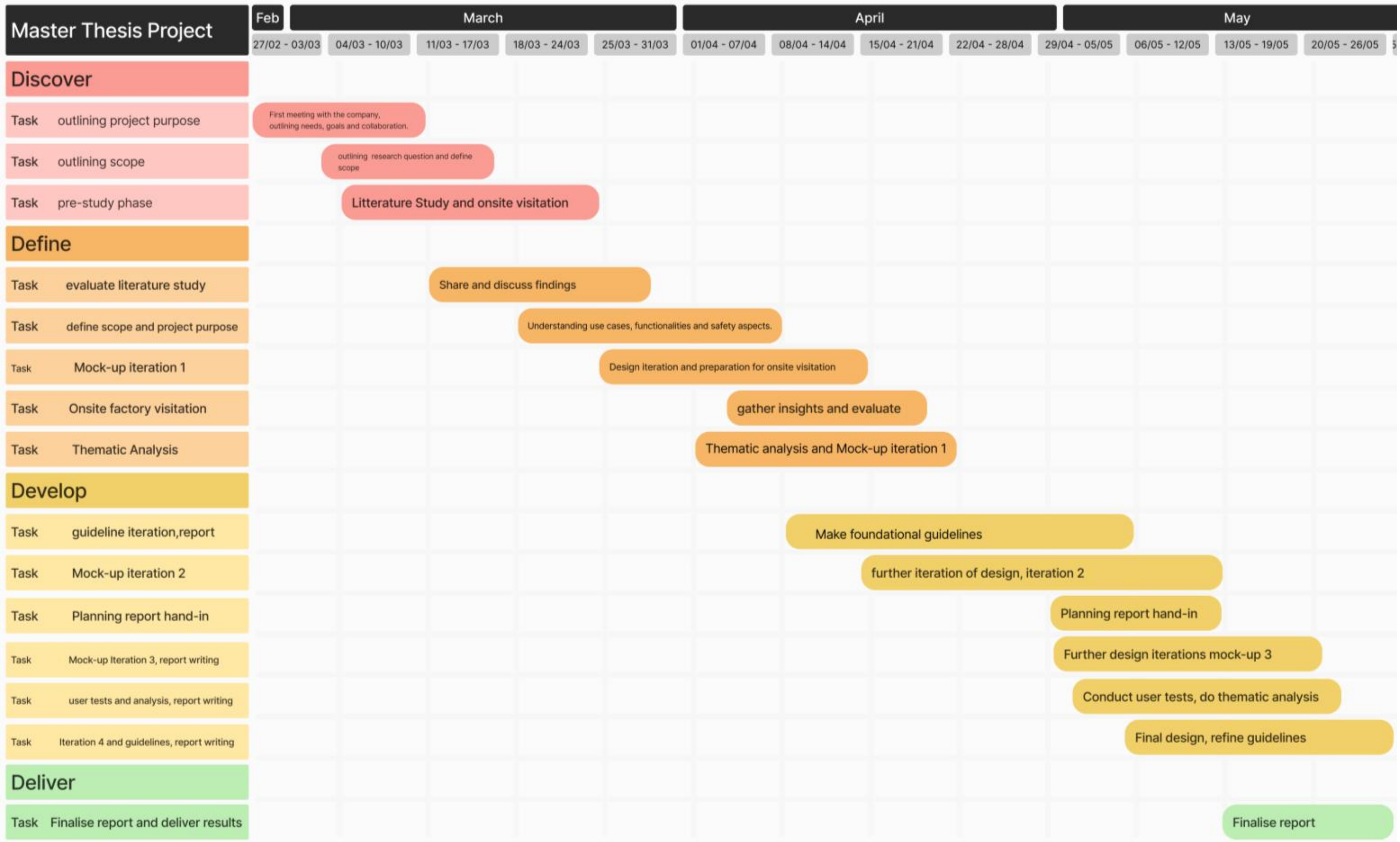

Figure 11: Gantt chart of intended project phases.

6.1.4 Result of Iteration One

In the following sections the result gathered from Iteration will be presented. Being the first iteration it is broad in nature, resulting in a wide range of different results.

6.1.4.1 Planning Report

As a result of the first iteration, a planning report was developed. A thorough description of the thesis will be conducted through earlier presented methods are described in the sections below. A Gantt chart was also created as a project management aid to facilitate planning, goals, and processes.

6.1.4.2 Double Diamond Utilisation

Another result was the decision to utilise the double diamond method. The following sub-chapters details how the method will be utilised throughout the project.

Discover

The first part of the project aimed to be focused on learning and understanding all relevant aspects related to the stakeholders and their machines, such as the capabilities of their products and use cases, but also everything related to their market and industry, observing how operators interact with them, to develop the baseline understanding necessary to be able to approach the thesis and study as desired.

Once a solid and broad foundation of information has been gathered, the plan is to start looking at more specific parts of the welding machine and its system. This is planned to be done by an onsite visitation at the stakeholder's factory, where observations and conversations must be done to get somewhat of an understanding of the possible interactions there are.

Numerous unofficial discussions have been conducted with different employees of the stakeholder, but more is required to feel comfortable with asking relevant interview questions further down the line. Effort will be made to get hold of customers, who the authors suspect might provide more genuine insights on the current HMI and welding system. Other than communicated insights, there is value in observing customers' interactions with the machine. It is suspected that there is a possibility that the customers might interact with these machines in another way than the stakeholders' employees. It is suspected that some parts of the

discovery phase will be limited since there is a HMI currently being developed, getting to interact and see this early on might affect how the authors approach the discovery phase. For example, some system capabilities that the HMI incorporates will be assumed to be correct and possible, resulting in an independent understanding on these specific parts of the system will not be gathered.
Based on this, it can be considered an exploratory study of a qualitative nature, through a case study, would be the most suitable method to answer the study's question and provide a design suggestion.

Continuing with the project the next step aims to be a qualitative case study. The main goal of a qualitative study is to differentiate this thesis study from already existing research. Access to stakeholders' documents has been somewhat restricted due to company regulations and the ongoing nature of the project. To compensate, an extensive literature study is planned to be conducted with the objective of extracting as much information as possible from prior research to support the thesis. When doing a literature study there is a possibility that previous problem areas defined by the authors can emerge and therefore be able to stay clear of those during our work. While being brought up in the Discover phase, the literature study is initially started here, but is brought though each phase.

All the articles and books used in the study have been gathered through Google Scholar and the library of Chalmers University. There was an effort made to find alternative sources to compare the information found so there could be more source criticism and have a broader understanding of contrasting concepts. Research within our area is somewhat limited in aspect to being well established research, it is important for the reliability of this thesis to acknowledge these limitations and utilise research selectively and with care. Sorting and selection of articles is based on the number of previous citations, journals the article is published through and how the literature is validated. This means that the credibility of the articles is based around what type of study it is built around.

Define

It is planned to conduct interviews with operators of the industry manufacturer's machines to further learn how they view the functionality and ease of use of current welding machines of the industry manufacturer, as well as how they experience the current interfaces. The industry manufacturer is moving towards minimising the time a human operator needs to spend interacting with their welding machines. But to do so their knowledge from an operator's perspective is preferable to be understood. Aiming to learn if there are undiscovered interactions that occur when the welding machine is used, and whether it can impact the use of the automated version in unexpected ways through performing contextual inquiries during onsite visitations. This can reveal what they need from the interaction to feel safe and secure about letting the machine work on its own.

The first part of the data analysis consisted of a thematic analysis. This was done on the data collected from interviews and documents. With this analysis method there can be accurate and sharp findings in the data. The advantages of thematic analysis are the possibility to modify it to fit the study and the method is easy to learn and utilise properly, which is an advantage for first time users of the analysis method (Nowell et al., 2017).

Develop

This part requires developing a mock-up of the HMI and to evaluate on operators to finally report problems or unwanted interaction behaviours. Further gathering insights required for the final design proposition. At the current state of the project the WOz technique is not yet considered to be an approach used during the user testing and evaluations. But there are a lot of criteria's that can affect this notion of excluding WOz. For example, if the prototyping and initial user tests proves successful resulting in an iteration of the design which could incorporate further aspects of the HMI a WOz situation could appear. At the same time if the software and hardware used for user testing will not be able to provide expected results and interactions, some type of "unseen operator" role such as a wizard might be relevant.

Deliver

For this thesis, the delivery phase will not be fully applicable to Gustafssons (2019) description of the phase. No launch and extensive evaluation will be performed during this phase. But the methodology of double diamond can be applicable to the testing of the mock-up of the HMI on operators as well as anchoring the suggested implementations to the industry manufacturer. Preparing the final design guidelines to hand-off to the stakeholders, including findings, concerns, and possibilities. Then consolidate the research contribution of interaction design principles implemented and used for the proposed HMI, as well as a final evaluation of the created design suggestions. This further differs from the commercial understanding of the delivery phase, as this thesis will not include production or launch of the suggested interface design.

6.1.4.3 First Draft of Guidelines

Finally, Iteration one resulted in a first draft of design guidelines, which were adopted from recommendations made by Opto22 (2014;2021). While these guidelines were broad and applicable to many domains, they served as a foundation for future iterations.

1. *Put data in context to increase the operator's situation awareness*.
2. *Make it easy by reducing the operator's cognitive load.*
3. *Build an information hierarchy that's easily navigated*.

6.2 Iteration Two

In Iteration two initial design guidelines were established through a thematic analysis of the previous interviews as well as already established literature within the realm of interface design. A total of ten guidelines will be iterated sporadically throughout the rest of the project (see Table 4). The guidelines build upon previously developed design guidelines by Ardanza, et al. (2019, p. 4046) and Opto22 (2014;2021) and are therefore broad in nature. This was to have a basis and direction for future guideline development.

6.2.1 Thematic Analysis of Focus Group Session

To create the next iteration of the mock-up and guidelines, all interviews needed to be analysed. Through transcription and translation, a set of citations were gathered, these were selected at first hand out from their level of relevance towards the project scope, either positive or negative. The citations were used in a thematic analysis framework, where common themes were identified, presented as below in table 3.

Table 3:Thematic analysis of interview data

Interview Thematic Analysis

Themes	Respondent Feedback	Discrepancies
In-system Support and Information	Implied a need for better support directly in the interface in terms of user guides or explanations. Desire for graphical views of weld seams and layer information to understand the remaining layers for clarity during welding. Suggestions for interactive info texts and visual dashboards to provide comprehensive information.	Three informants felt the symbols were easy to understand, while three felt the same symbols were confusing
Error Log and Error Messages	Respondents emphasised the need for an improvement in terms of error messages and the feedback from the system, with clearer error codes and alerts in order to manage issues effectively. There was also a suggestion to include light alert for noticing errors more easily.	
Parameter Monitoring	An expressed need to have more information about the system status and its operations in terms of monitoring parameters like voltage, current and wire feed speed in real-time. Suggestions for alerts for low supplies like wire or flux to prevent interruptions in welding.	
HMI Mockup Navigation	There was a difficulty in understanding and navigating through the mock-up of the HMI, particularly for certain terminologies or icons that did not adhere to international standards.	Two informants felt that due to previous generations of the HMI not differentiating much, the current used one was easy to learn how to use.
Colours, Contrast, and Visual Aesthetics	Informants reported concerns of the visual layers, contrast and use of colours, wanting a more clear and contrasting colour scheme. Dark mode was seen as visually pleasing.	
Recipes Functionality	Informants reported challenges utilising the recipe management system, wanting a more intuitive process as the current process was too time demanding.	Three informants does not use recipes in they daily work and did not consider as an important of a function to be more comprehensive, while four felt it would greatly benefit it the recipe management got more consideration in terms of development.

By using thematic analysis, we were able to structure a lot of qualitative data gathered from all informants. Despite identifying discrepancies in the informant’s experience of the interface, such as opinion and view of icon and button design, it was decided to overlook independent opinions at this stage and focus on the majority of consensus towards the overall structure, design, and available interactive elements. The majority's opinions were too overwhelming to consider occasional contradictory opinions. With this in mind, it is not to say that individual opinions were to be overlooked when continuing the thesis research. Why we at this stage felt comfortable with overseeing certain opinions is because of the range of background experience the informants possessed. Informants with more relevant welding experience weight more than those with less. Since at this part of the process it was the everyday users who were in focus. Despite a few differences they had, most of the times similar overall opinion on both interview questions and experience with the mock-up.

Iteration of guidelines

The first iteration of guidelines was created with a foundation of design guidelines earlier presented in this thesis, along with our own design suggestions and with the feedback received by the informants after the interviews. By creating this iteration directly after we were able to visualise what the informants feedback had for effect on the overall design.

Table 4: Iteration Two of Guidelines

Iteration of Design Guidelines

Guideline	Description
1. Enhance Situation Awareness	Put the data in context to enhance the operator's situation awareness by displaying relevant information that helps operators understand the current state of the system.
2. Reduce Cognitive Load	Make the interface intuitive and straightforward to reduce the operator's cognitive load, ensuring that information is easy to find and understand, especially for new customers or those unfamiliar with company-specific terminologies.
3. Create an Information Hierarchy	Build an easily navigable information hierarchy that allows operators to quickly access critical information, using logical organisation of views and settings. Ensure minimal, logically organised pages to facilitate ease of navigation, with essential welding parameters centralised on the main page.
4. Support Real-Time Monitoring and Control	Facilitate real-time monitoring and visualisation of critical parameters such as voltage, current, and speed. Ensure the interface allows for both automated settings and quick manual adjustments.
5. Optimise Visual Layout	Design a clear, contrasting colour scheme, including a dark mode option for better readability in different settings or for different preferences. Utilise distinguishable colours for different states, ensuring readability and adherence to colour contrast standards.
6. Improve Error Handling and Feedback	Enhance error messages and system feedback with clear error codes and alerts. Offer interactive info texts to help operators diagnose and resolve issues effectively.
7. Incorporate Visual Icons	Enhance error messages and system feedback with clear error codes and alerts. Offer interactive info texts to help operators diagnose and resolve issues effectively.
8. Design for Experience level	Utilise icons to visualise information, making it easier for operators to understand and interact with the HMI regardless of experience level or language. Incorporate internationally recognized symbols for user-friendliness.
9. Integrate Support and Training	Incorporate user guides or explanations within the interface to provide ongoing support. Ensure operators have easy access to information about system status, operations, and troubleshooting.
10. Incorporate Visual Alerts	Provide visual alerts for the HMI in critical situations, such as low flux, low wire, system malfunction, or other issues to ensure operators can address problems timely.

Iteration of Mock-up

This iteration while incorporating design principles from various researchers and teachings within graphical design, it focused more on the feedback and bringing it to life. This iteration was also only limited to the “main welding” view. This limitation came because this iteration was merely a visualisation of feedback, to help us as a guide continuing.

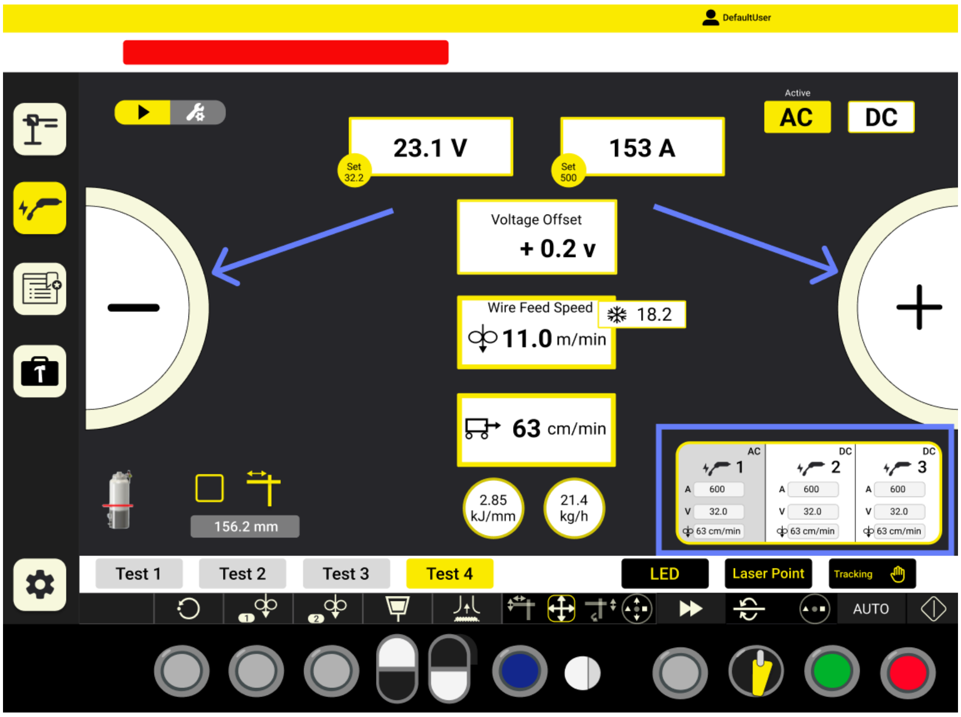

Figure 12: Iteration 2 Main Welding View. Blue arrows and sections are not part of the interface.

The interface shown in (Figure 12) is an iteration of the (Figure 9) previously shown.

Welding Head Navigation

The first design change here to be discussed is the decision to have separate views for the welding heads. This change is due observations and insights provided by informants. Shortly after the interviews, we took part in a demo of a welding operation. This demo was simply showing the welding machine with three welding heads weld at a straight line for about one metre. While being interesting to experience and see, the important finding came from observing the operator interact with the system and machine. The machine used for the demo had three separate HMIs, one that controls and oversees each welding head. Our initial thought was that that must be inefficient and frustrating to operate, but the operator mentioned that the only real inefficiency with this setup was that it demanded a lot of space. Nothing indicated that the operator had any major issue with overseeing and operating the three HMI. This was the finding that led to placing an overview of the welding heads in the blue section, were operators have an overview of the welding heads associate parameters and is interactable to switch between the welding heads.

Interactive buttons

The second set of observation and feedback lead to the half-circle buttons the blue arrows (see Figure 12) points to, which has the capabilities of manipulating the values of Voltage (V), Ampere (A), Voltage offset, Wire feed speed and welding speed (63cm/min). Looking back at the initial iteration (see Figure 9), there were separate buttons for each possible interaction and manipulation of values. Since as earlier discussed we found no good enough reason to keep all welding heads at the same view, therefore we would be able to utilise the space more efficiently by allowing the same buttons to manipulate different values. Keeping a consistency to manipulate values. Now instead the operator would have to touch the desired parameter and then add or decrease with the half-circle buttons. The shape and placement of these buttons came from an observation of the display intended to be used for the HMI combined with findings gathered from the interviews. The informants described that an important aspect of the HMI is that they should be able to manipulate values on the HMI, while keeping an eye on the welder. Meaning if an operator needs to adjust a parameter they want to see it with their own eyes, not just look at what the interface communicates. To do this accurately would be difficult with the first iteration because the size of the buttons was too small to ensure accurate manipulation. Secondly the placement built upon this idea as well as observing the display being formed as a large touchpad, we thought of users being able to hold the display as a touchpad and accessing the half circle buttons with their thumbs.

6.2.2 Result of Iteration Two

Iteration two consists of a lot of differences and changes from iteration one. But as mentioned many of these changes is solely based on personal preference or visualization of ideas we choose not to go in on detail on all changes in this chapter. Iteration three will go in on detail of each design choice with related reasoning. Table 5 provides an overview of the changes done in this iteration.

Table 5: Design changes from iteration one

Design Changes from Iteration 1

Changes	Reasoning	Goal	Limitations
Background Colour and overall colour theme	Personal preferences, and utilised core colours	Decrease visual stimulation and amplify use of core colour consistency	Limited research and potential bias in informants opinion
Divide welding heads to separate views	Observation and conversations found that multiple welding heads on one view was unnecessary	Limiting potential interactions to the most crucial	Need more demo observations to fully support
Button design (manipulating values)	Utilising the touchscreen size to amplify important interactions	Facilitate use of crucial interactions	Faulty reasoning for half circle
Element placing	Focus users attention to important aspects of the HMI	Make the interface digestible and easy navigated	Design principles not followed
Add and removal of Available information	Informants described important and less important aspects shown in the mockup	To present thoughtful information at required time and place	Informants description from their use cases are not applicable to all users.

6.3 Iteration Three

The third iteration of the prototype had several stages of smaller iterations, being the version requiring more refinement as it would need to incorporate all findings from earlier phases as well as to be able to visualise and stand as a support of our design guidelines. This iteration was used for the user testing, which meant it included more thoughtfulness than iteration two by incorporating design elements from the stakeholders HMI, design choices based on feedback from informants, as well as design elements obtained from design methodologies, earlier research and design theory presented in this thesis. As such, the process of moving forward from the second iteration to the third and final iteration will be defined below.

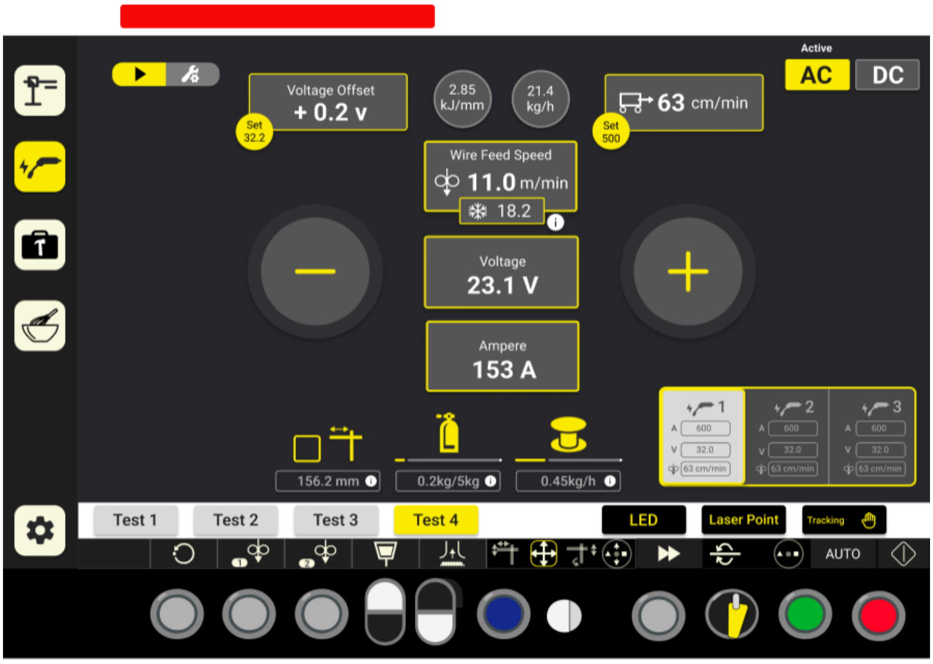

Figure 13: Main Welding View of iteration three.

Button Design

The first change to be discussed when going from the earlier iteration are the buttons that alter the values, such as increasing volt or ampere (see Figure 13). As previously discussed, part of the reasoning behind larger increase and decrease buttons placed along the edge was for if the HMI would be able to be handheld, thus it would create a more comfortable and easier interaction. Further, as the increase and decrease of important parameters were reported to be most utilised by the informants, it could benefit from having more screen real estate. However, as the side menu would take screen real estate on the left, it could easily be unintentionally pressed. It was therefore decided to minimise the buttons and placing them more in the centre, thus also aligning with our own design guidelines (see Table 4) about enhance situational awareness. Keeping the important interactions and values in the centre of the operator's attention. By keeping the buttons relatively large we hope to cater for operators that use protective gloves in their working environment, which we wouldn't have the possibility to test if even possible. And this size aims to increase the accuracy of interactions.

Colours

The previous iterations were designed to cater for a light-on-dark scheme, but it was not a consistent utilisation across all views, and thorough considerations regarding the over-all use of colour in the HMI mock-up had not yet been made, e.g. as many elements still had a dark-on-light scheme. To keep consistency and adhere to the project identity, the third iteration was designed with this in mind, keeping the gradients, hues and contrast consistent across all views with referencing to a colour scheme that had been made for another project in the stakeholder company made by UX consultants for that project.

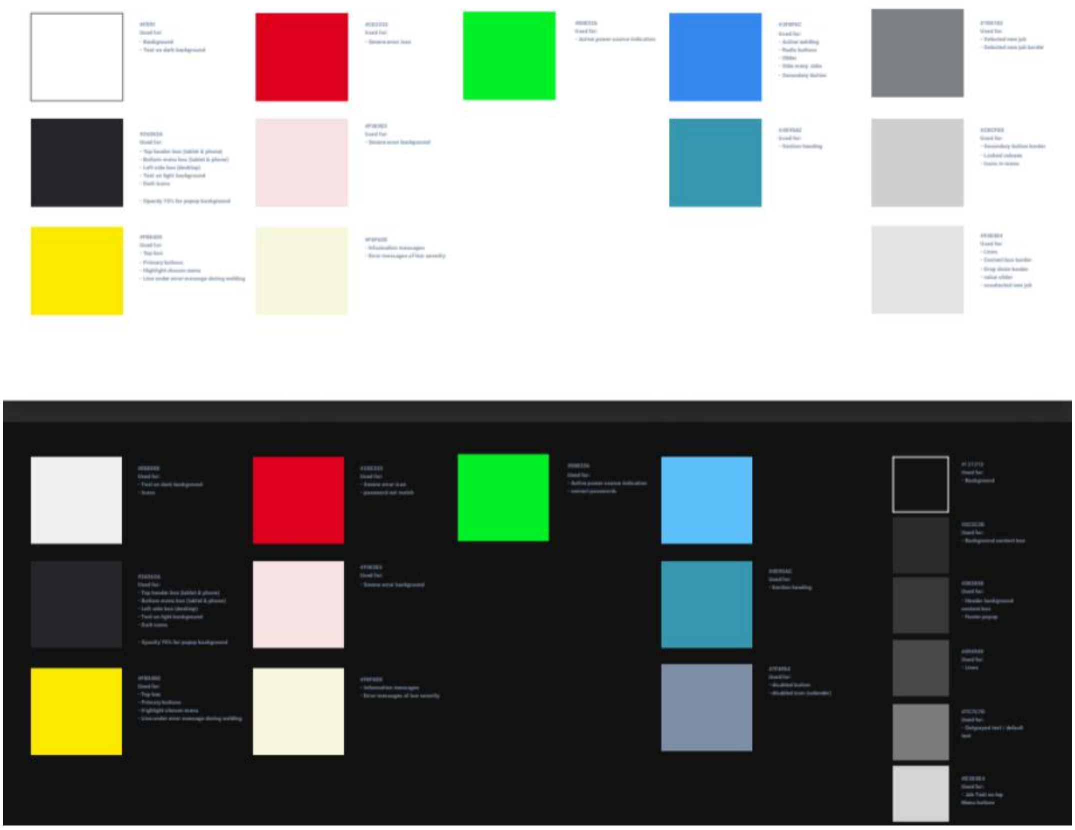

Figure 14: Colour Scheme for the HMI mock-up.

Guidelines for how to apply colour in design in pervious chapters of this thesis states it is important to use colour coding as it reinforces the hierarchy of information, but also communicates the established visual language and adds cohesion to the project identity. Thus, it was important in this stage to utilise the colour scheme mindfully, ensuring such guidelines were followed.

Recipe Creation

Recipe management previously was nestled within nonrelated functions (see Figure 10). The informants expressed a need for improvement of recipe management and creation to even consider utilising its capabilities (see Table 3). When asked about the current recipe management, three informants said that they probably wouldn't use it even if done correctly while four informants expressed that it could be useful if improved. This feedback, together with positive feedback of the process of recipe creation from user tests, a functioning recipe management process was incorporated into the scope, as the informants expressed that if designed correctly it could be incredibly useful and improve the overall user experience of interacting with the welding machine. Operators would be able to set commonly used parameters and combine them in different recipes specific for different use cases.

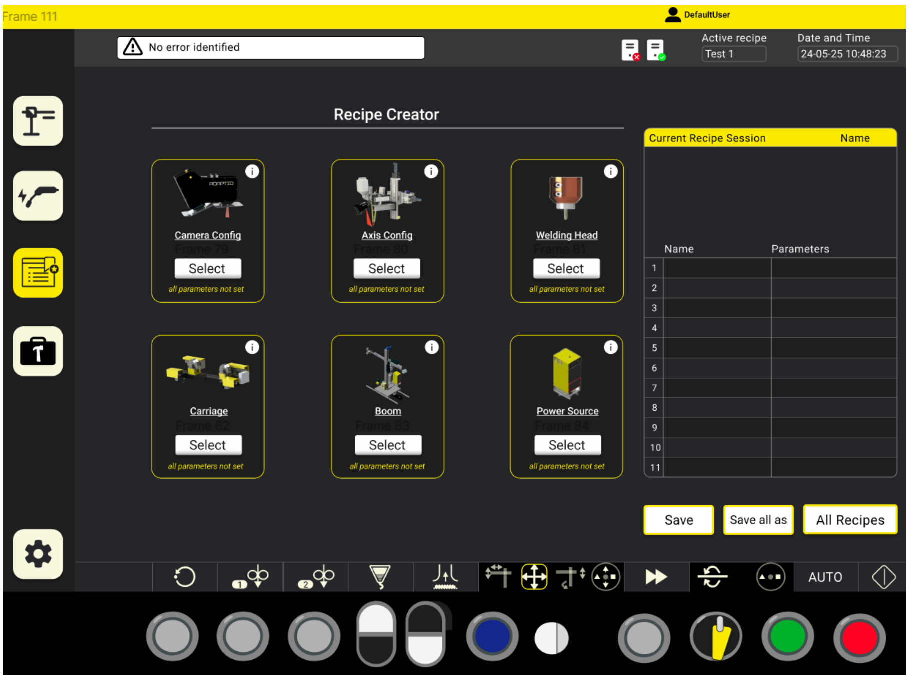

Figure 15: Start of the recipe creation process.

To facilitate the recipe management, it was decided to separate the process of creating and managing recipes from the standard machine settings. Informants from the user tests expressed

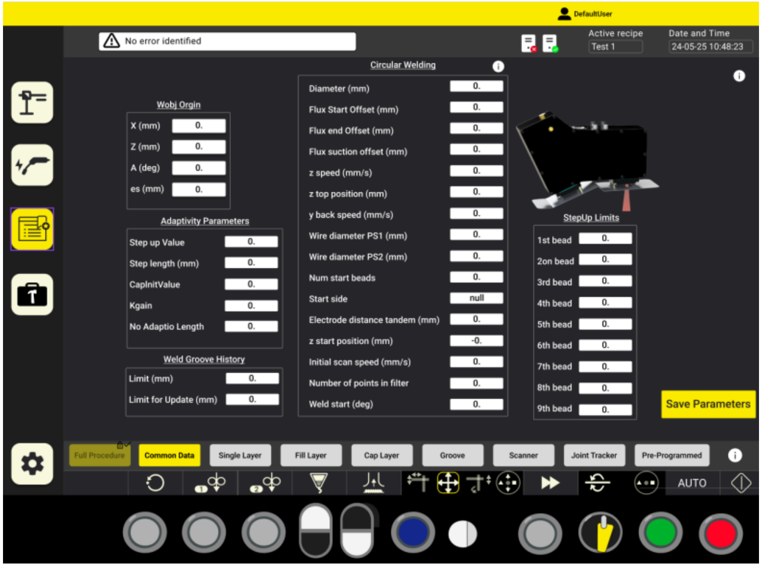

Figure 16: Recipe camera settings

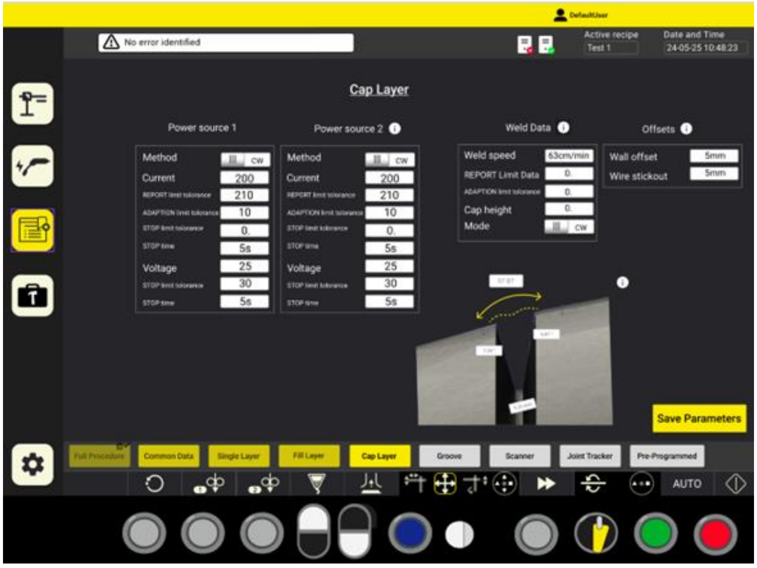

Figure 17: shows how the user has continued through the process and reached the Cap Layer

uncertainty of whether how they could save the parameters as a recipe or explicitly implement them to the machine, which was an experience shared with the representative responsible for the HMI as well. With a separate recipe management flow, it was intended to enhance the user experience by creating a clear navigational flow, that through straightforward communication indicates to the user what should be done to complete the task.

As an example (see Figure 15), when the user selects “Camera Config,” they must go through a couple of steps by filling in parameters that they wish to add to a recipe (see Figures 16 & 17). While being views that incorporate a lot of information that might be overwhelming, which cannot be changed due to stakeholder requirements, the enhancement of a clear path to what is needed to be done can make the process feel more digestible. In addition to this, the bottom bar communicates to the user where they are in the process and what is left to be done. To move along the process, the user fills the parameters and then clicks “Save Parameters.”.

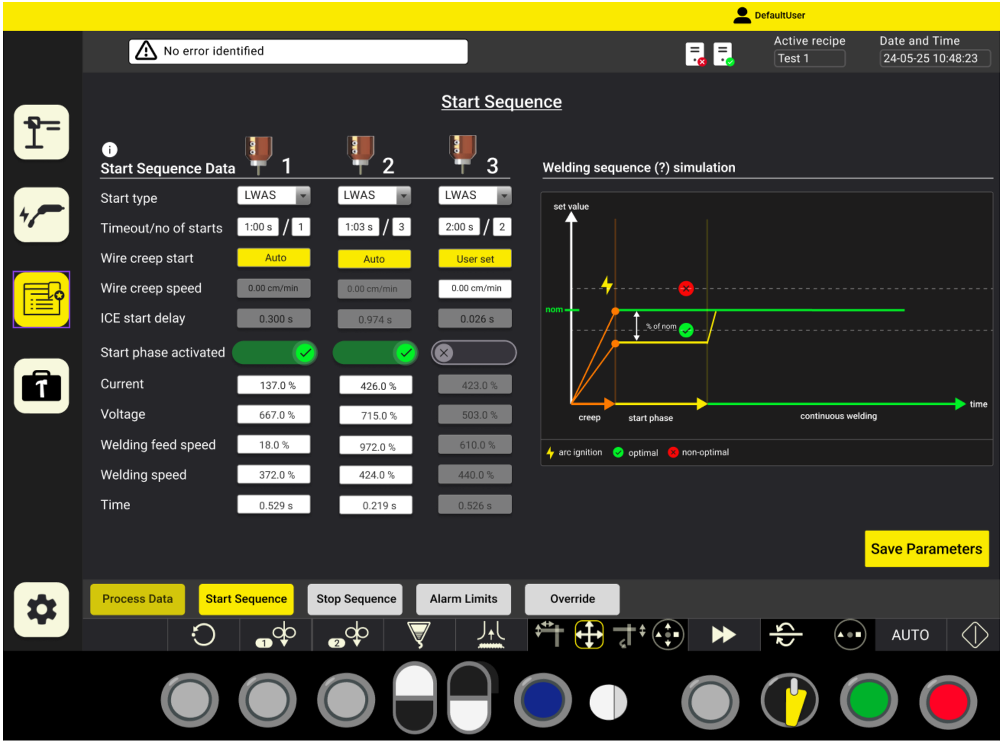

Figure 18: Welding Head Parameters and Simulation.

Once the user has completed all parameters for essential configuration, the user can move on to the “Welding head” (see Figure 18). These parameters settings incorporate a function that is unique compared to the other parts of the system. This view provides the users with real time visualisation of how their parameter inputs will, in this instance, affect the welding head start sequence. Where if the user changes a parameter to the left, the simulation will reflect the change in real time. As the user changes anything the diagram on the right will translate these parameters into real time visualisations.

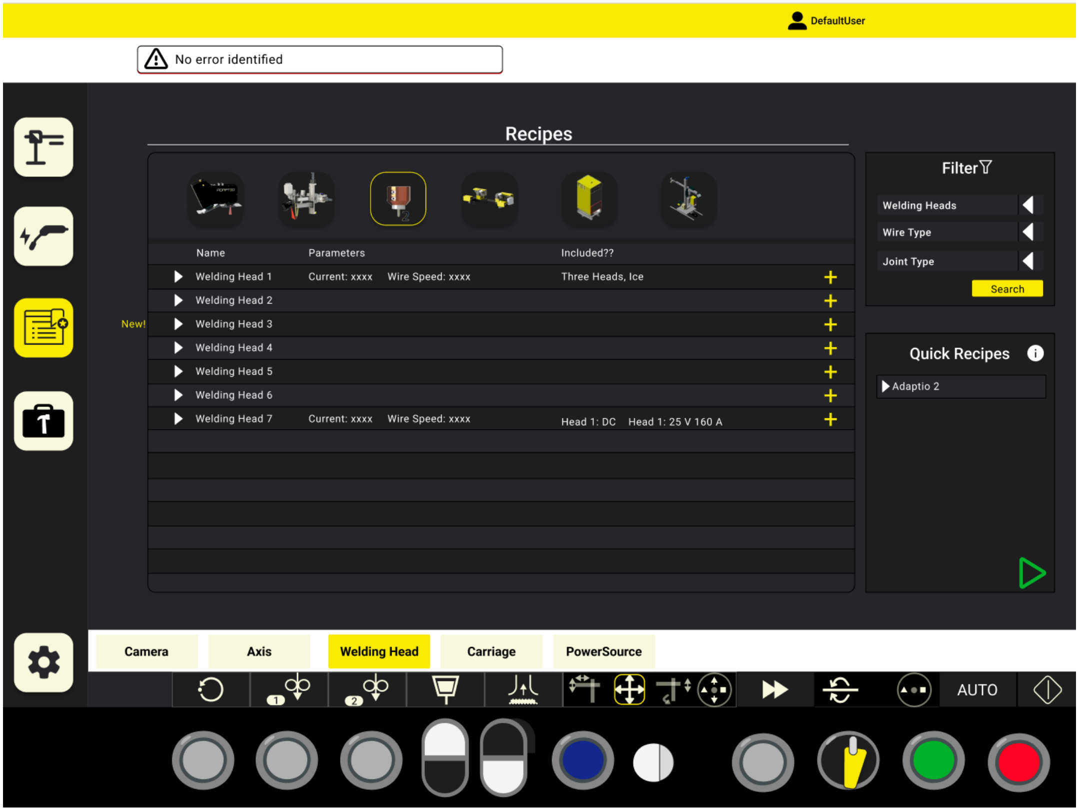

Figure 19: All Recipes View.

Once the user has completed the process of creating a recipe, they can navigate to the "saved recipes" view. This view contains the new and old recipes, separated by what component the recipe was created for (see Figure 20). This was done to distinguish the recipes from each other, providing icons for clarity. The user can also click the plus symbol to add the recipe to "Quick Recipes." This function loads the recipes added on the bottom bar of the main view, facilitating ease of access for recipes most utilised. The user can also filter the recipes, based on the welding heads included, wire type, and joint type, as this was communicated by informants to be a usable function.

Figure 20: Menu icons in Iteration one (left), Iteration two (middle), and Iteration three (right)

Side menu

Several iterations were needed for the side menu. This was due to some critical factors, one being that the contents of the menu had to be carefully considered, as it would heavily impact the navigation capabilities of the entire HMI. There were also uncertainties of what should be accessible within the menu. Findings from the interviews, showing the first iteration of the HMI mock-up (see Figure 10), indicated that navigating to the recipe settings within the overarching settings menu was tedious, especially considering the nestling of the function within other parameter settings. In iteration two, it was therefore added on the side menu for better accessibility (see Figure 21, middle). The icon used in this iteration was a play on words for recipe, visually indicating the functionality of the menu button. From the user testing sessions, it was observed that all informants could navigate to the recipe creation view with ease. In the third iteration (see Figure 21, right) of the mock-up, a more appropriate icon was used, combining a list icon with a bookmark icon which can generate the intention of creating the association of "saved," and "collection."

6.3.1 Selection for User tests

To validate the third iteration and identify areas of improvements as well as its strengths, several user tests were conducted. The user tests included insights from seven informants. The reasoning for stopping at this number was due to most informants having similarities in their feedback, thus not providing new insights that could be applied in development. While new insights could have been attained by testing informants familiar with the company's other products and HMIs, there were limitations in terms of accessibility for such tests as mentioned in the previous chapters.

In total seven informants participated in the user tests. The selection of informants for the user tests utilised convenience sampling. This was due to distance, time, and the limitations in terms of user group. This resulted in having informants for the user tests from varying backgrounds, but with a commonality of having a background in- or experience of working with UX or IT development, apart from informant one who instead had prior welding experience, and one informant is currently working in the automotive industry focusing on the manufacturing of automation. As such, it can also be seen as a form of purposive sampling and convenience sampling combined.

Table 6: ser test informants and professional background

User Tests

Informant	**Background**
Informant 1	Service Technician in Automotives
Informant 2	Management and Manufacturing Consult in Automotive Industry
Informant 3	IT Automation and Environment Developer
Informant 4	Software Engineer
Informant 5	Software Engineer in Infotainment
Informant 6	Head of IT and IT Security
Informant 7	Frontend Developer

This test aimed to provide insights from another industry to see if it could be applied to the objective of this study. It was initially planned to conduct the user tests with only those familiar with the stakeholders current HMI and the relevant machines. However, it was found during the first interview session that a consistent view of the current HMI by the informants was that new users would likely find it difficult to familiarise themselves with the interface as the complexity of the data had increased, compared to older versions, thus needing the new HMI to be more user-friendly. Having informants with little or no welding experience participate in the user tests was therefore relevant for the continuation of the development of the HMI. This decision was also communicated with the stakeholders who agreed the relevancy of conducting user tests with a variety of backgrounds to gather an understanding if the final prototype included enough user-friendly elements to allow inexperienced users to complete a series of scenarios and tasks. While this thesis could have benefitted from user tests within the stakeholder company as well, there were some limitations in terms of time and location to conduct such tests, as the most relevant location to visit the stakeholder was remote and planning to conduct visitation took considerable time.

Like the first interview sessions, the user tests had semi-structured questions but with an emphasis on observation of interaction behaviour performed by the informants. The users were tasked with completing several scenarios and tests (see Appendix, C). Examples of tasks the informants had to complete was to attempt to increase and decrease the voltage and ampere, followed by asking the informant to identify the impact of the increase and decrease action when looking at the interface. Other examples of tasks were related to navigation within the interface, such as using menus and buttons to progress in the setup of certain parameters. Having the informants perform tasks and asking them questions that related to their understanding of the interactions provided valuable insights in how well the interactions could be understood (see Appendix, B).

6.3.2 Thematic Analysis User tests

Using thematic analysis as a data analysis method is suitable for this research because of its capabilities to adapt and be utilised for very specific research questions that other methods can’t achieve. The first step of this process was to systematically search for codes or small aspects of the transcribed material that later could build themes. This was done separately to increase the level of reliability of the collected findings. The value of doing the coding separately as a crucial part to reach more reliability, since it decreases the prospect of personal bias, and perception and instead provides a more collective view that correctly represents the qualitative data gathered. Using thematic analysis findings that could be related to the research question were identified. This is one of the advantages of thematic analysis, as the method serves as a great tool to identify meanings of qualitative data that otherwise might be overlooked which later could be shown as critical for the research at hand.

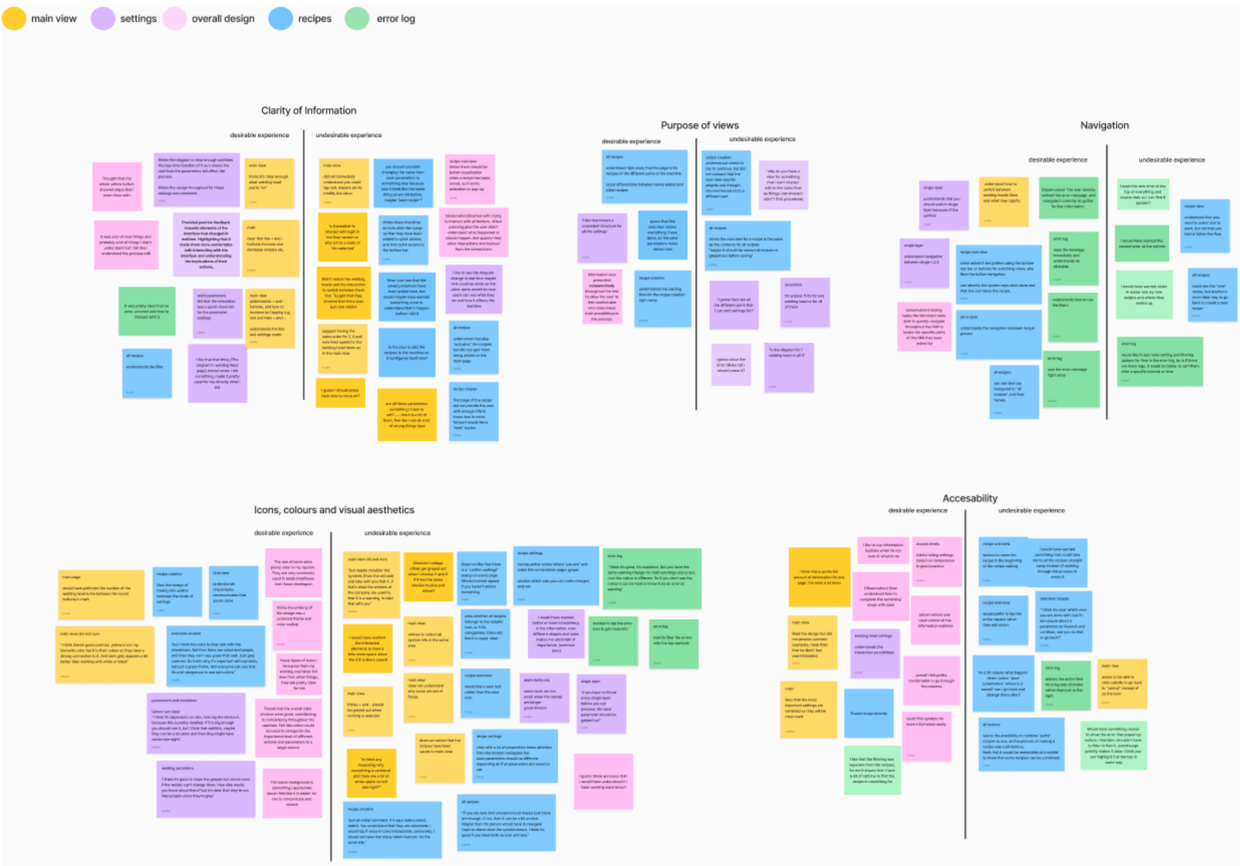

Figure 21: Thematic analysis and groupings from user tests.

The thematic analysis resulted in five themes: Clarity of Information, Purpose of Views, Navigation, Icons, colours, and aesthetics, and Accessibility. These themes were also colour coded according to which views the feedback was related to, such as the main welding view, recipe creation, error log, and more. The feedback was also divided by 'desirable experience' and 'undesirable experience,' to see which areas more clearly had more positive or negative feedback. The coding facilitated the translation and meanings of the communicated data received by informants but also and most importantly supported and/or helped to iterate the initial guidelines.

6.3.3 Result of Iteration Three

Iteration three served as crucial step to specify design guidelines for our research. By developing a third iteration built on more considerations in terms of design choices, results from interviews, and literature, it was initially seen as the last iteration necessary and that it should only be used in the user test to help us further develop the design guidelines. However, as the user tests went on it soon became clear a fourth iteration would be required due to many improvements and blind spots in the design being identified by the informants. While the third phase helped increase the understanding of what modern design principles should be utilised to answer the research question, it was recognised that the design guidelines were much to open and non-specific to fully make a knowledge contribution. It was therefore decided to work on a final iteration of the mock-up to refine the design and identify elements within it to specify the design guidelines even further.

6.4 Iteration Four

The final iteration is a product of everything that has been done up to this point but from interviews, observations, user tests and established design principles. This iteration also argues for the defined design guidelines we have brought forward during this thesis project.

Table 7:Design changes from iteration three

Design Changes from Iteration 3

Changes	Reasoning	Goal	Limitations
Refinement of recipe management with one view for recipe creation, and one for recipe library	Informants desired to be able to create "combined" and "component" recipes	provide the ability for operators to have more control of recipe creation depending on situation or needs of the user	Uncertainties for if the system would support the functionality
Further refinement of recipe menu icon that is more common, with text for further clarification	Previous icon was a placeholder and was not recognised in the domain of welding	Provide more clarity of what the menu button contains	Is made within Figma and not a standardised symbol within the domain of welding
Further adherence to dark-on-light colour scheme	Some elements, like the top and bottom bar, were still in a dark-on-light colour scheme.	Make the entirety of the mockup cohesive	?
Further additions of information within the HMI mockup	informants desired more information within the views for certain functions	Provide more clarity of functionalities and interaction possibilities	?
New recipe creator starting page, with the addition of walkthrough mode	Informants wanted adjustments in terms of how to start the recipe creation process	provide adaptability of recipe creation depending on situation or needs of the user	Uncertainties for if the actual system would support the functionality
New symbols for flux and wire	Informants reported uncertainty of previous symbols meaning	provide better visual repsentation that would be recognised within the domain of welding	Is made within Figma and not a standardised symbol within the domain of welding
changing hue of some buttons from yellow to grey	was not entierly clear when some buttons were or weren't interctable	Visualise more clearly when a button is or isn't interctable	?

The changes made between iteration three and four might seem minimal and detailed, but we argue that exactly these types of changes are important to bring forward our final design guidelines. The development between iterations one and four highlights the advantages of having a human centred approach, even as the systems become increasingly autonomous.

Figure 22: Iteration four Main view of welding.

6.4.1 Design Changes in Iteration Four

The most notable change made from iteration three was the introduction of separating the recipe library by component recipes and combined recipes. As expressed by informants, there was confusion about whether a created recipe contained the combination of components of the welding system, or if you could only save recipes for each component separately. An informant from the stakeholder company also expressed that the ability to customise whether a recipe can contain all or only some components would be beneficial, for example to separate recipes by the kind of wire thread, so that no recipe gets accidentally selected. This is a crucial factor to consider when it comes to usability engineering as previously presented in this thesis, where considerations to be made include identifying the tasks that users need to perform with the welding machines and designing the interface to support these tasks effectively. Therefore, the Library was divided into a tabular design, to clarify to the user more easily where they are positioned and what they are seeing (with information icons?)

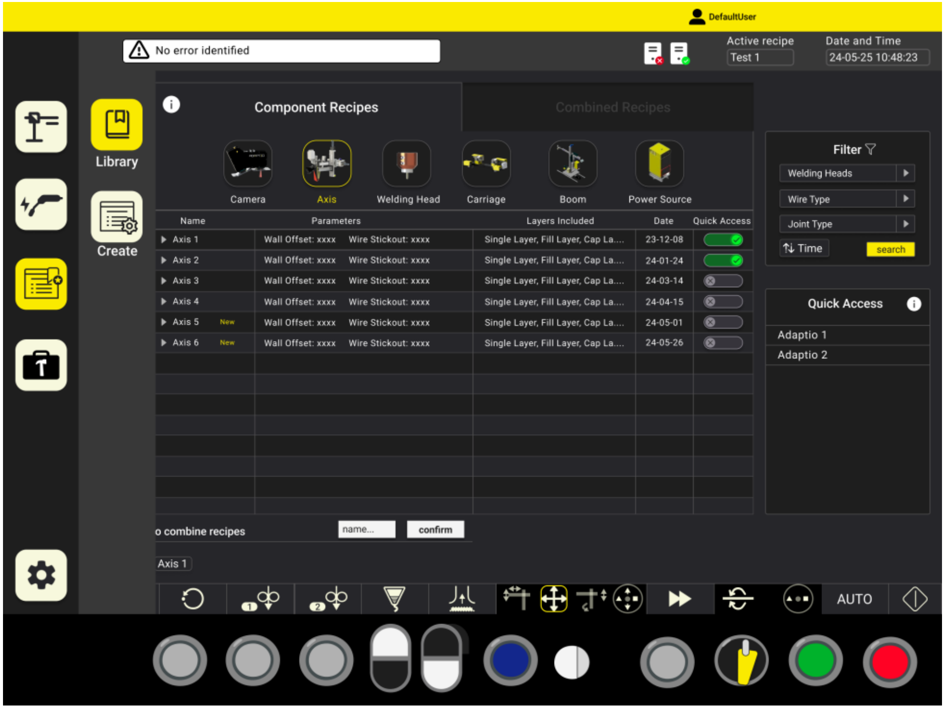

Figure 23: Component Recipes view.

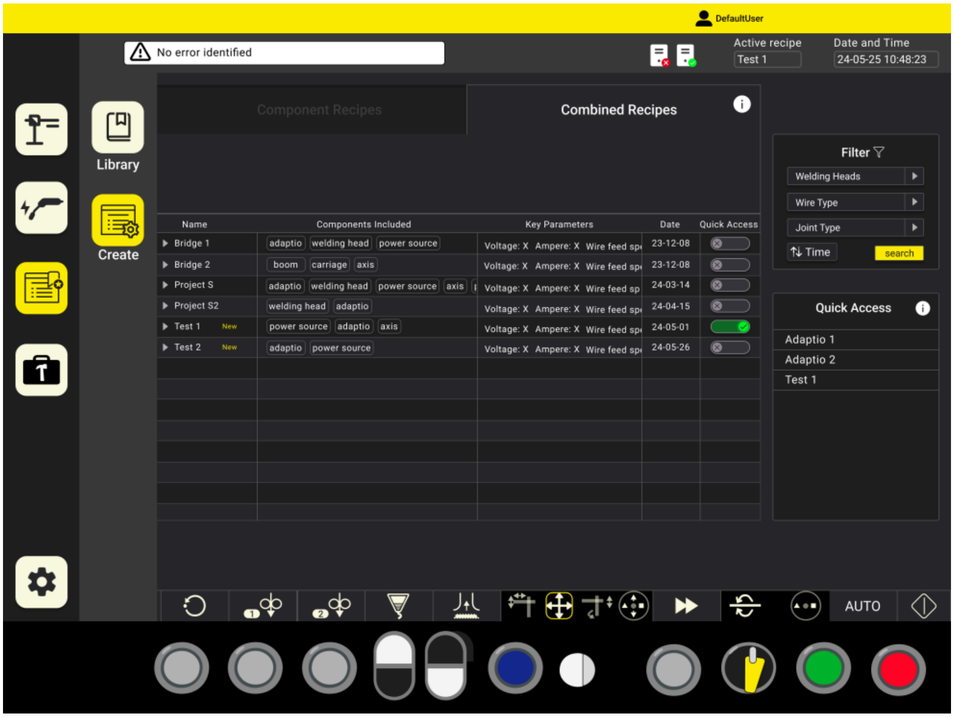

Figure 24: Combined Recipes view.

These design choices further aligned with our foundational design guidelines, being to reduce the operators cognitive load by ensuring that information is easy to find and understand, as well as to ensure there exists an easily navigable information hierarchy using logical organisation of views and settings. A last addition to the recipe creation views were the addition of a new starting view (see Figure 25).

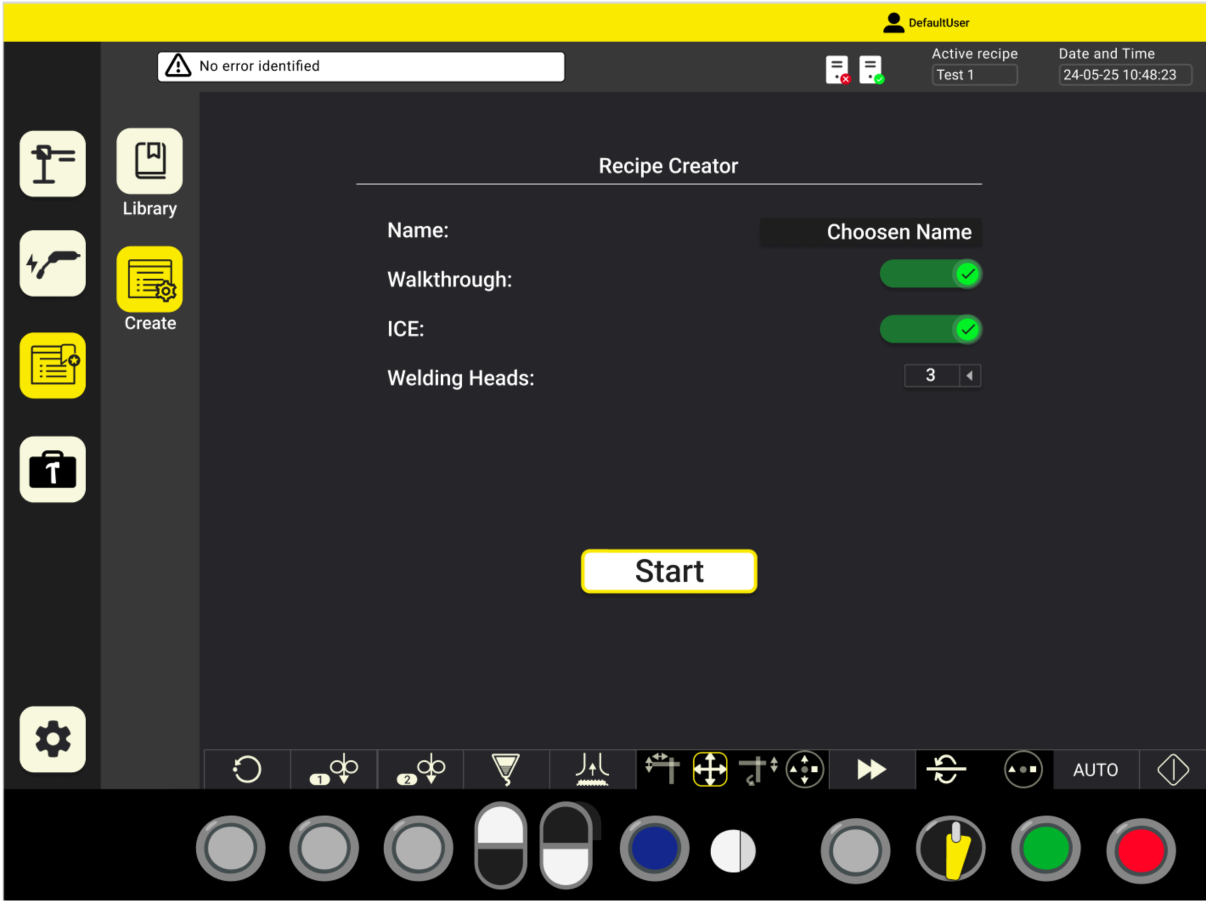

Figure 25: Recipe Creator Starting View.

New icons

Along the change to the recipe views, two menu buttons for library and recipe creation were added to facilitate better access to both views, which further ensured that the guideline of using icons to visualise information to make it easier for operators to understand and interact with the HMI were followed. The icons used for the views were made within Figma, where Library uses the iconography of a book and bookmark to indicate the library view, and the list with a gear to represent the recipe creation view.

Figure 26: Menu icons for Recipe Library (top) and Create Recipe (bottom)

The icons were also accompanied with a keyword to further clarify their functionality. As previously stated in this thesis, while concrete icons that relates to everyday objects or experiences can be helpful for users to understand their function, keywords should also be added if users are new or unfamiliar with the icon to further clarify its functionality. As the icons for recipe creation and library were created in Figma, and therefore not a universally recognised symbol or not used in the domain of welding to the authors of this thesis knowledge, keywords were added below the icons to clarify their functions.

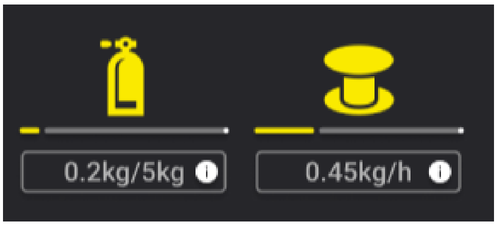

Figure 27: Icons from iteration three (left) and wire thread (right).

New icons for flux and wire thread were also made. These icons were similarly made in Figma, using the principle of using concrete icons that relates to everyday objects or experiences. The icons are a more accurate representation of the flux container and flux thread. The change was also affected by Informants response to the icons during the user tests, as the symbol for flux was confused for gas, and the symbol for wire thread was confused for a game console joystick and therefore required the fourth iteration to incorporate more consideration of the visual communication of these icons.

Theme and colour adhesion improvements

Some last alterations of the overall design were made to adhere to the project identity and overall colour scheme. These changes were mostly related to the top and bottom bars of each view, from white to a hue of grey.

Figure 28: White-on-dark theme changes between iteration three (left) and four (right).

Another change came from informants desiring more information and clarifications within the interface. One such element was that it created confusion when the yellow outline indicated an interactable state, despite another element being selected. As such, the fourth iteration made other elements take up less attention from the selected element, by greying them out. This change follows the guideline of putting data into context to increase the operator's operational awareness, highlighting critical information, and letting less important data be in the background.

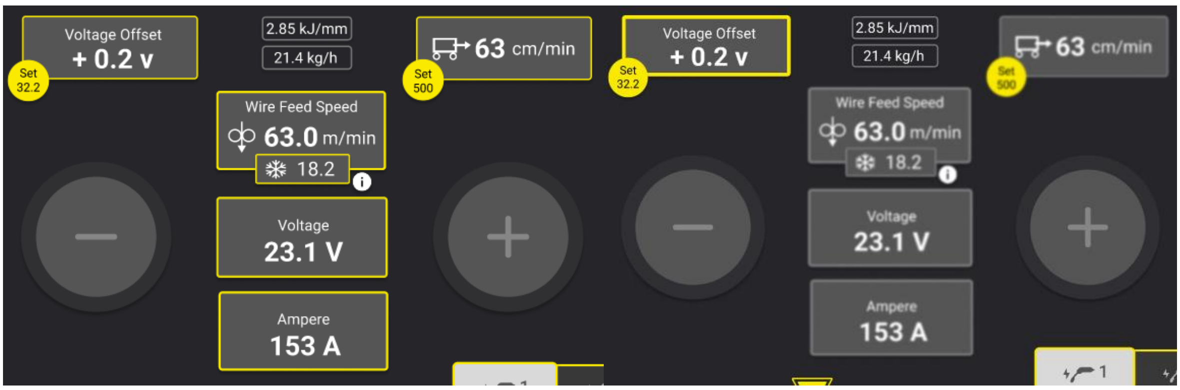

Figure 29: Greying out buttons that are not selected.

6.4.2 Result of Iteration Four

The fourth iteration contained a lot of fine tuning of the mock-up design, incorporating feedback from user tests as well as from the thematic analysis, where most notes stemmed from the theme ‘Icons, colours, and visual aesthetics.’ Another result from the fourth iteration was a refinement of the design guidelines, becoming more specific as the thematic analysis and previous iterations helped pinpoint the specific aspects of the design that were seen as positive and negative. As such, the entirety of the HMI mock-up and final guidelines will be presented in the subsequent chapter below.

As discussed earlier in iteration one, the initial research question was a placeholder and we articulated the reasoning behind the initial research question (see Section 6.1.1). As we progressed, it became evident that some aspects of the research question would be challenging to address. To fully understand and validate whether our HMI facilitates automation, we would need to conduct tests with the HMI integrated into a real system.

Given this limitation, we decided to iterate our research question based on the insights and results gathered. Since we could not directly address the facilitation of automation, we refined our research question to better align with the work completed. The revised research question is: “What modern user interface design principles should be considered when designing the Human-Machine Interface (HMI) of industrial welding machines?” This question is more suitable for the scope and findings of our project.

7. Result

This chapter will present the most important views of the interface as well as their contents. This chapter will also include the results of the iterated guidelines, where examples from theory, methodology, and the mock-up provides additional context and to supports the recommendations.

7.1 HMI Mock-up

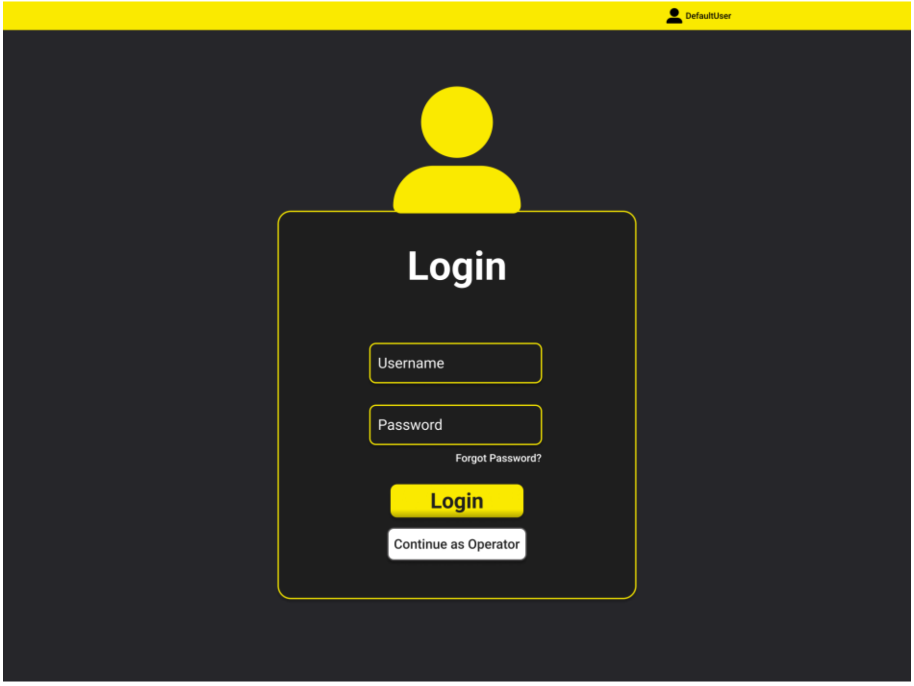

Figure 30: User Login Views.

The initial view of the Mock-up is a login view for the user. Either continue as an operator or input their login information. Operators access only the basic parameter settings, while users with login information have accessibility to more specific parameter settings.

Figure 31: Main Welding View.

The Main Welding View is the view that operators will be exposed to while a welding process is ongoing (see Figure 31). This view provides a clear overview of all the important parameters that the operator can manipulate during welding. It consists of multiple interactive elements which allows the operator to accomplish a variety of changes to the system. The blue square consists of interactive elements which allows the operator to change Voltage, Ampere, Wire Feed Speed, Offset and Welding Speed (direction). The circles are used to change the value the operator has selected. The arrow is the part of the interface which allows operators to get an overview of the different welding head status. Once a operator identify that they need to manipulate a value for a different welding head they would just select the desired one, and then the elements shown in the blue square is related to the selected welding head. The red square visualises information about the direction of the welder is moving, how much flux is left and how much wire is left. On the left in the green square is the menu, which allows operator to navigate between different parts of the system and to communicate on which view the operator currently are by the yellow button.

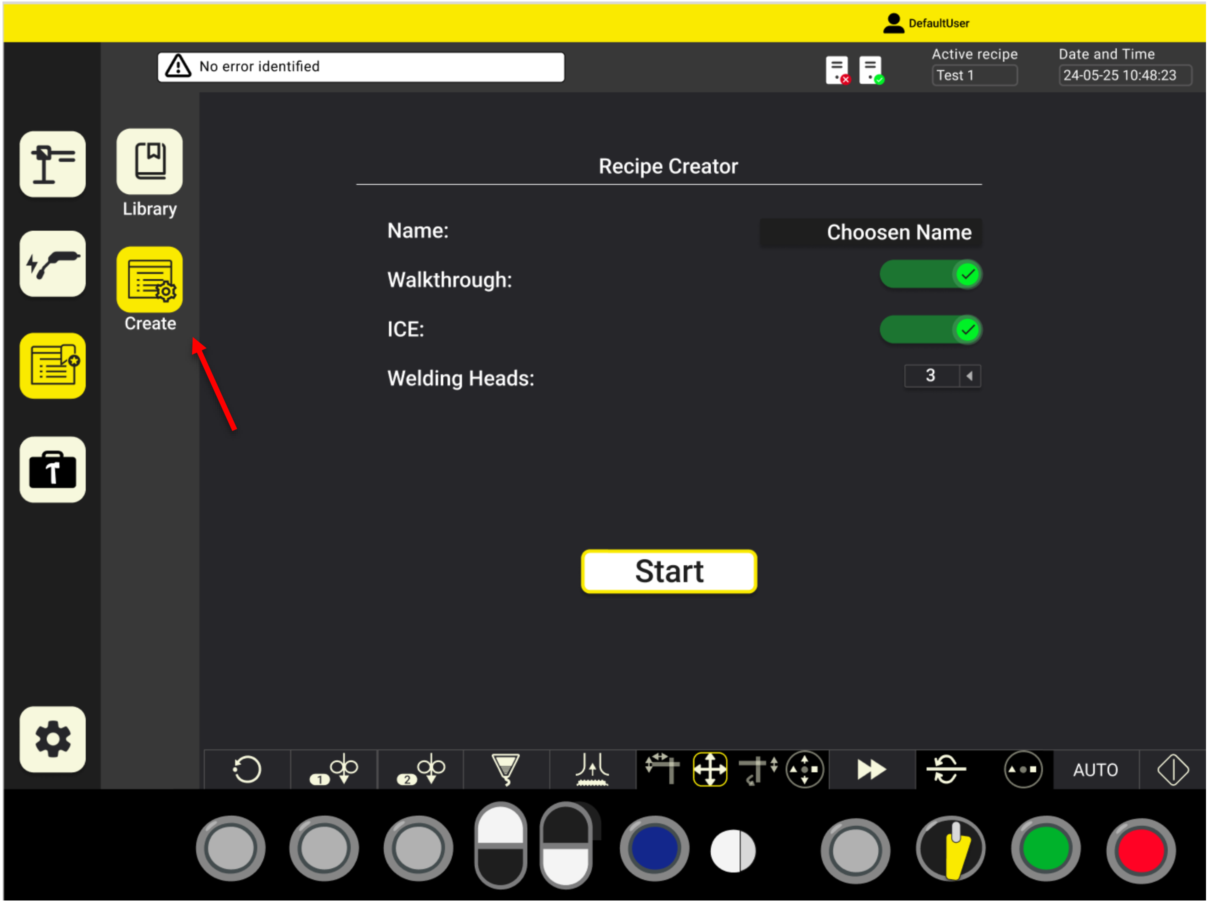

Figure 32: Recipe Creation Starting View.

Here the operator has through the side menu navigated to the recipe management, and more specifically to the recipe creator (see Figure 32). The side menu expands to give access to additional options when possible. At this view the process of creating recipes is started. After inputting a name, the view also presents a few settings that determines what the next steps will contain. Such as if the operator would want a walkthrough, this means that the operator will get more hints and clarity in the next steps than operators who deactivate it will get. Secondly is the amount of welding heads the machine has or the amount that the operator wants to include in the recipe creation. Once the desired information has been added, the operator would press start to get to the next step.

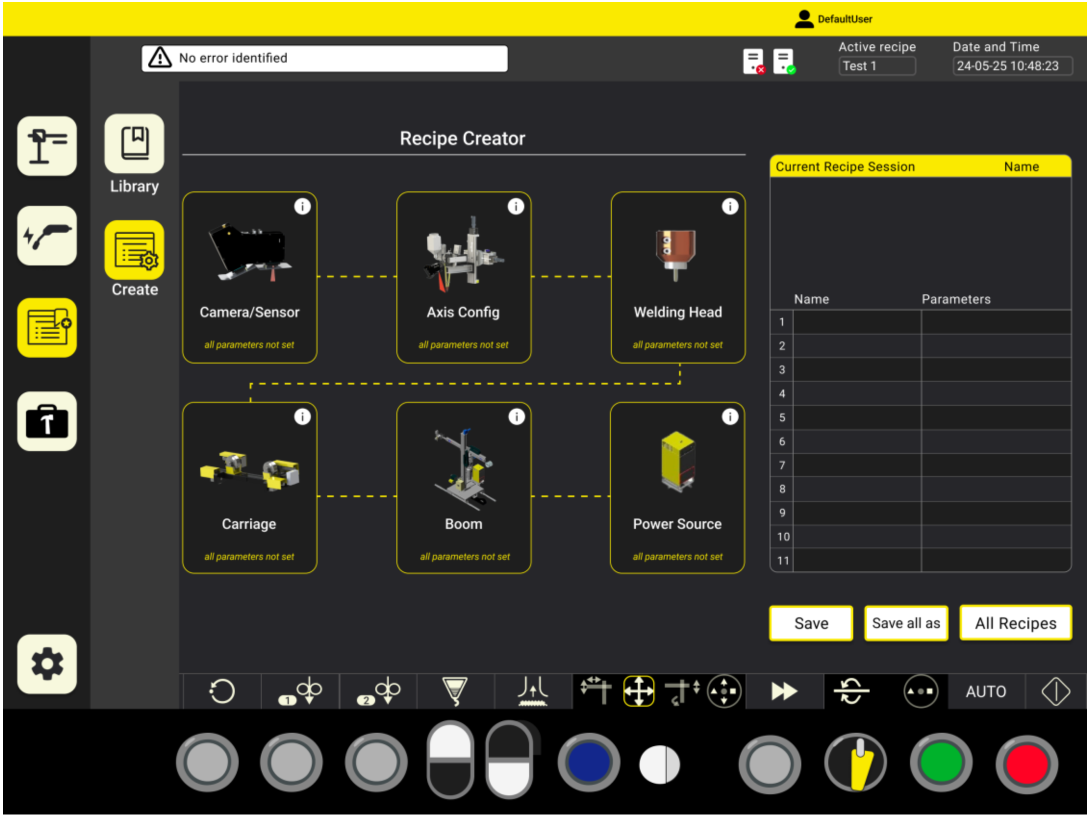

Figure 33: Recipe Creation overview view.

Figure 33 contains the view for the Recipe Creator. Here, the user can start the recipe progress by tapping each card for the components (outlined in yellow). The "Current Recipe Session" list is to provide the user with an overview of the recipes that has been added. For users who wishes to set parameters for all components, they can either follow the flow as illustrated by the dashed lines, or freely navigate to the component they desire to configure. The user can also tap the information icons for each component to see more information about each component.

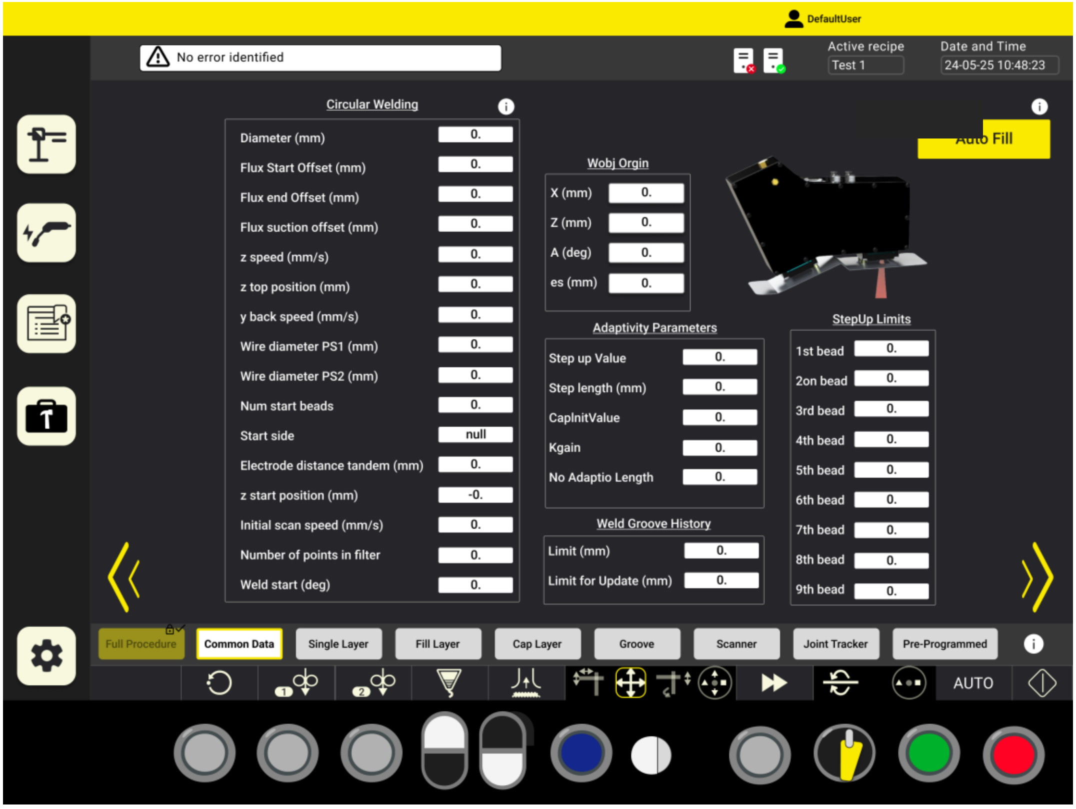

Figure 34: Recipe Camera Parameter settings view.

In Figure 34, the user can set the parameters for the camera. To progress or move back to the previous view, the user can either use the yellow arrows to move or navigate directly to the desired parameter settings in the bottom navigation bar.

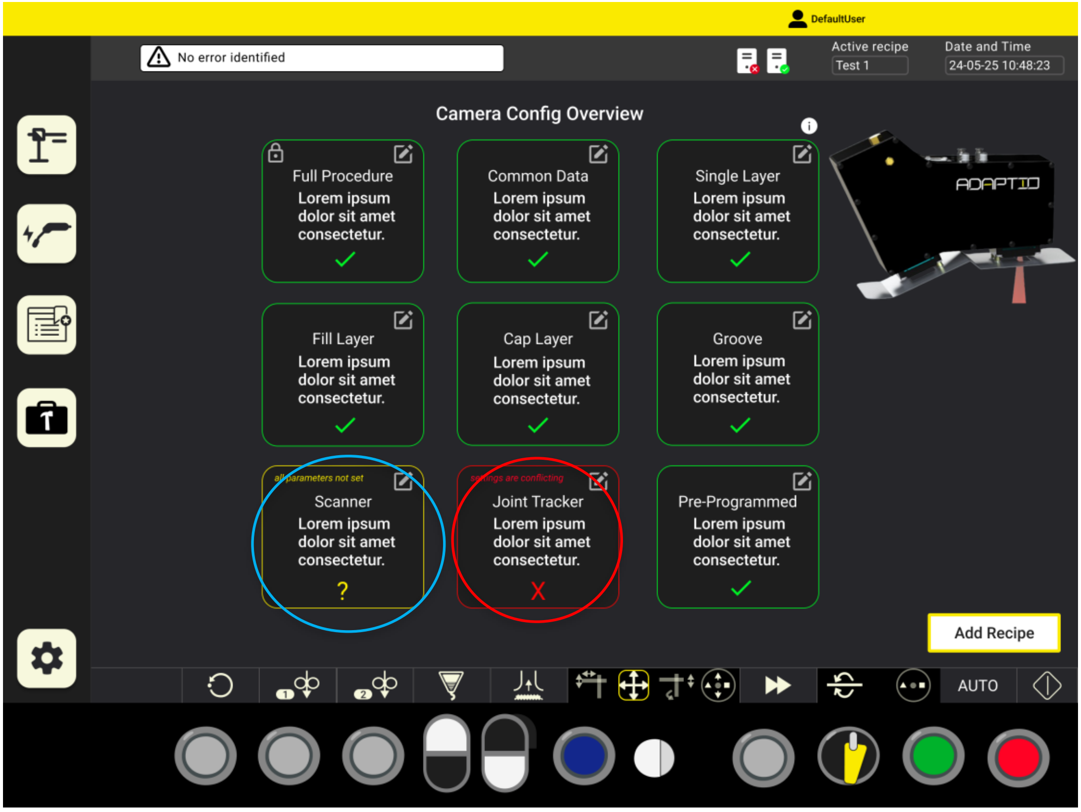

Figure 35: Overview of all parameters set for the camera.

After the user has set all the parameters, they will see an overview (Figure 35). If the user has not filled out all parameters in a view (blue circle), of if there are conflicting settings (red circle), the user will be indicated by symbols, text and colour change in the element to be notified.

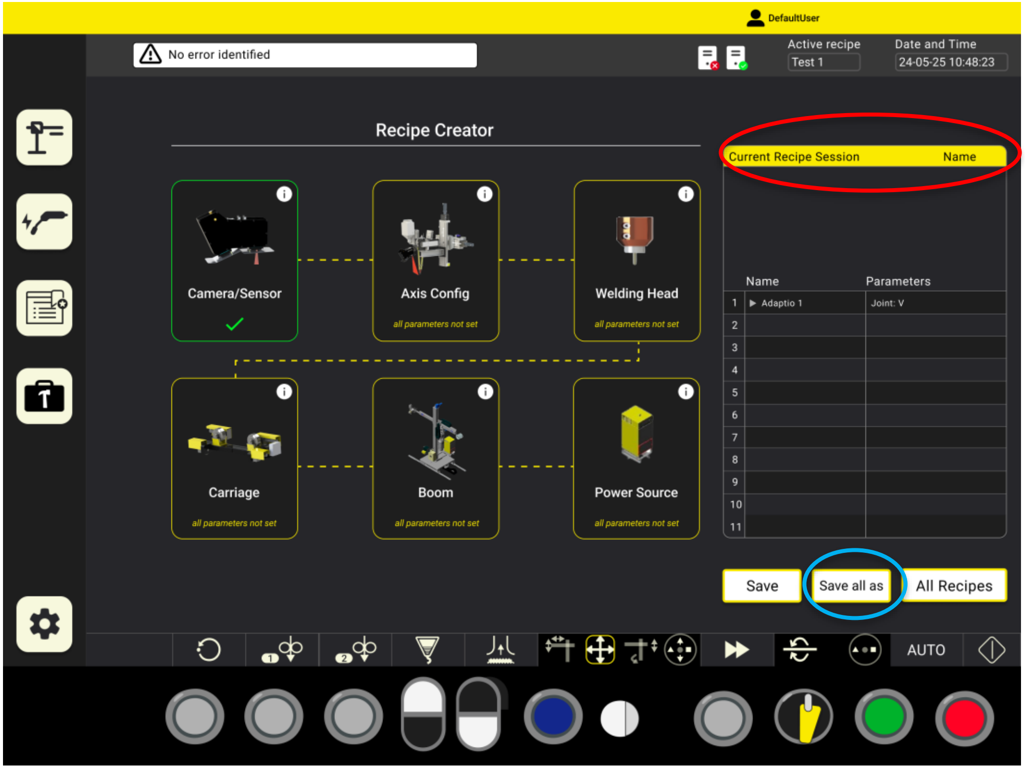

Figure 36: Recipe Creation Overview progress example one.

In Figure 36, the user can see that they have completed the setup for the camera, indicated by the green checkmark and colour change of the outline. The user can also now see that their recipe for the camera has been added to the “current recipe session” list (red circle) to have an overview throughout the process.

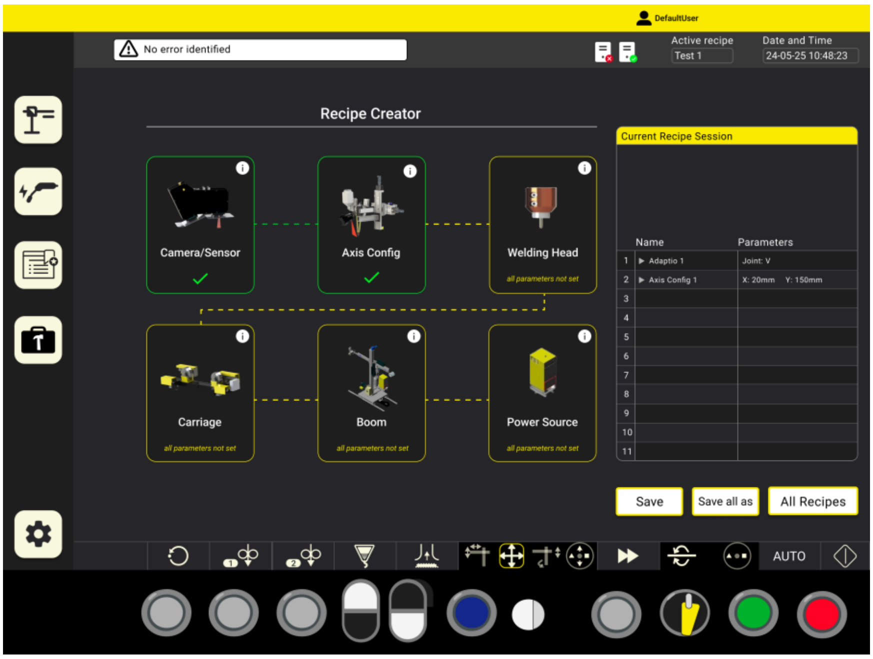

Figure 37: Recipe Creation Overview progress example two.

As seen in Figure 37, the user will see the same change for each component as they go forward in the process. If the user wishes, they can navigate to the “all recipes” view at any time, if they do not require to create a recipe for all components (blue circle).

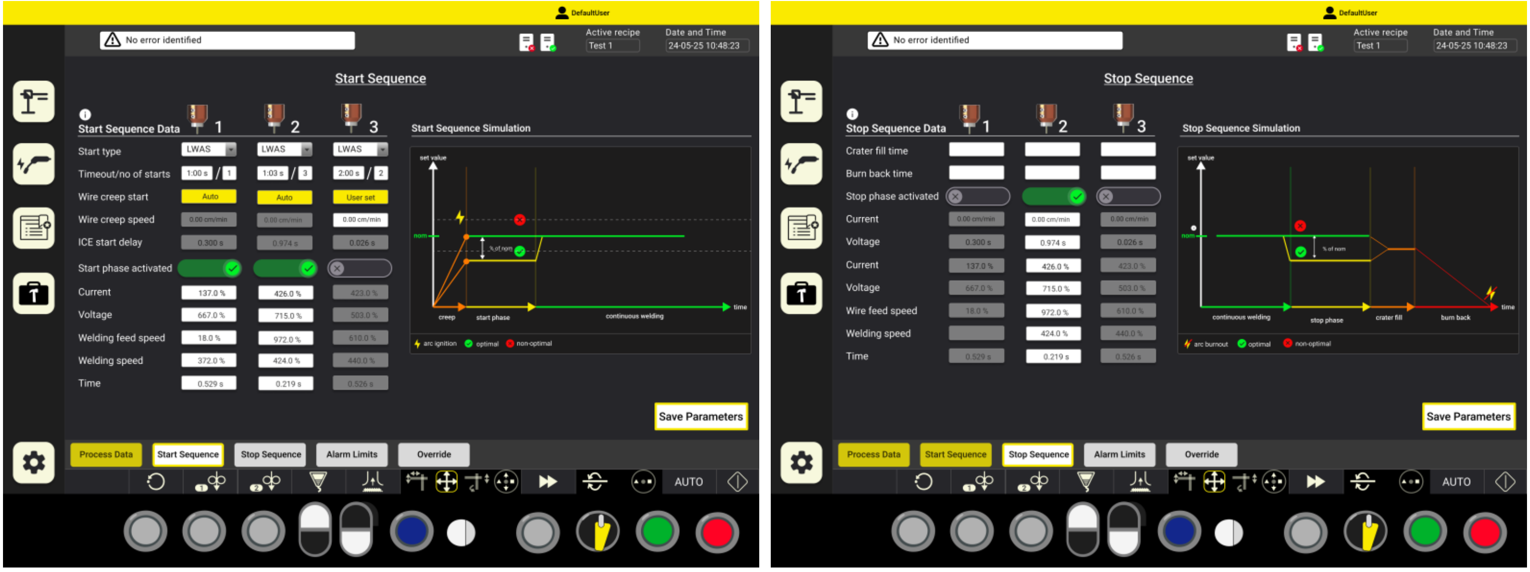

Figure 38:Recipe Welding head Parameter Settings and real-time simulation for the start sequence (left) and stop sequence (right)

Figure 38 contains the view for setting the welding head parameters. In these settings, the user can also see the real-time sequence simulation of the settings, detailing how the settings will affect the start (left) and end (right) sequence of the welding. The simulation also contains icons and their implications through text.

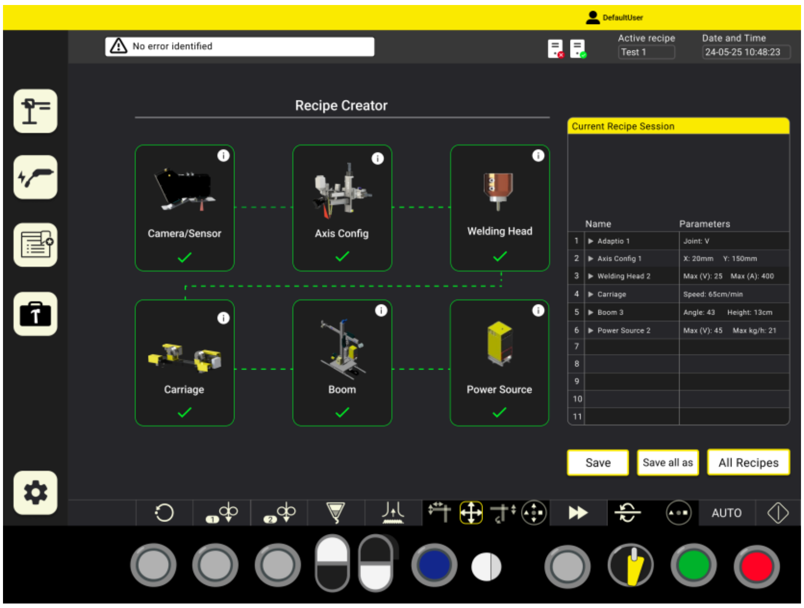

Figure 39:Recipe Overview all parameters set.

Figure 39 contains the view for when all parameters for each component has been set. The user can now save recipes or select “save all as” to combine them into one recipe (Figure 40). The user will get a popup notification to confirm or cancel the action.

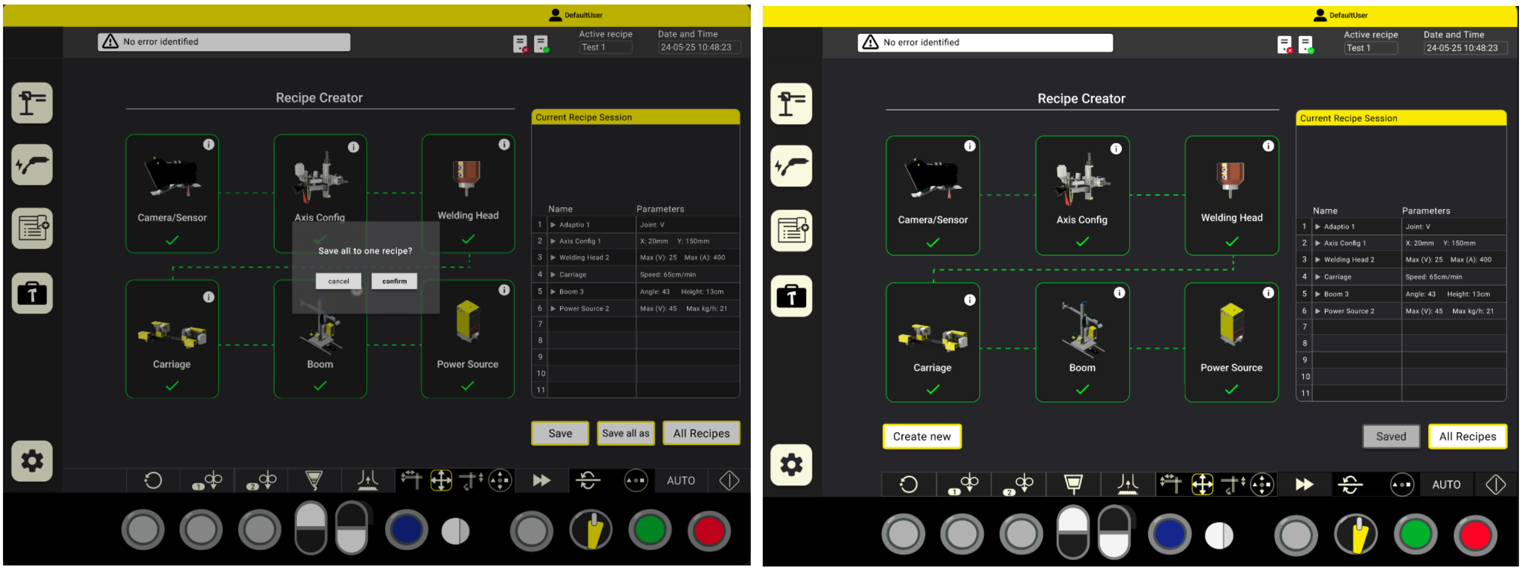

Figure 40: Save Recipe to Components (save) or save all as Combined (saved all as).

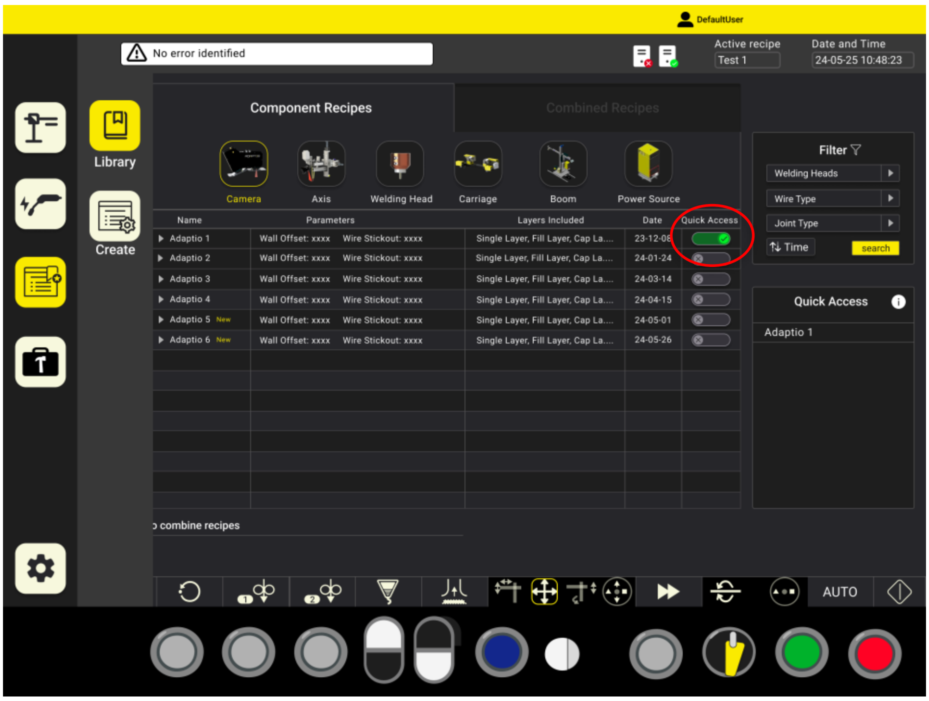

Figure 41: Recipe Library; component recipe overview.

In this view, the user can see all recipes that are specific to one component. In Figure.41, the recipes that has been created for “Camera” are placed in a list view, where new recipes are marked by a “new” text. The user can switch between different components, such as Axis, to see its respective recipes as well. On the right (red circle), the user can add recipes to “Quick Access” which will add the recipe in the bottom navigation bar on the main welding view.

Figure 42: Recipe added to bottom bar of main welding view

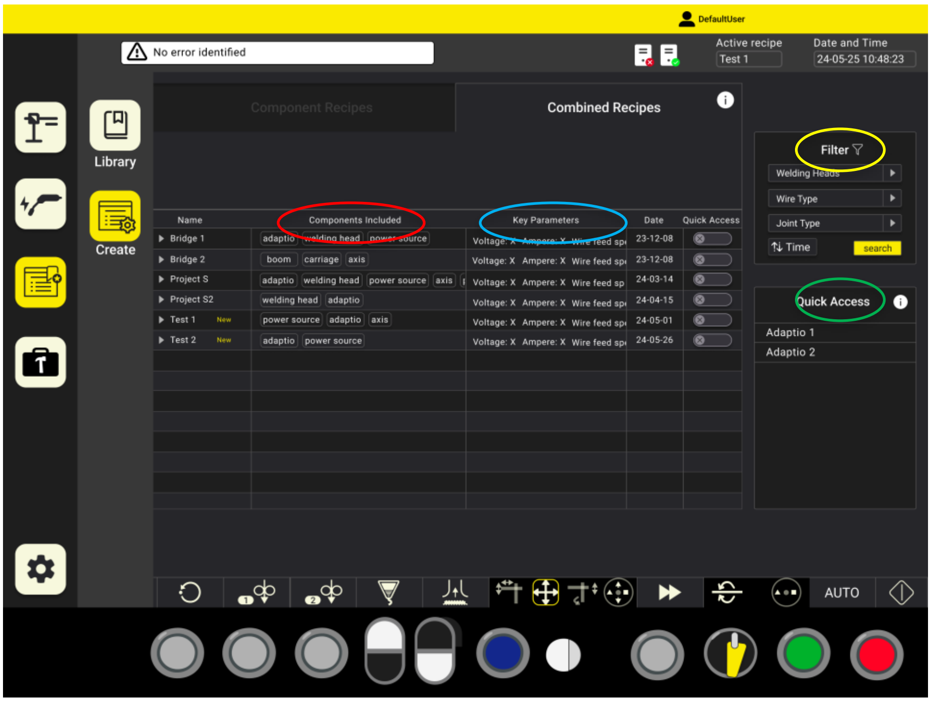

Figure 43: Recipe Library; Combined recipes overview.

By switching to the other tab in the recipe view, the user can see “Combined Recipes”, which contains recipes that has several component recipes combined. The user can see which components are included in the recipe (red circle), the critical parameters (blue circle) and add them to Quick Access (green circle). For both tabs of the recipe view, the user can use the filter menu to filter recipes based on which welding heads are included, what wire type, and what joint type (yellow circle).

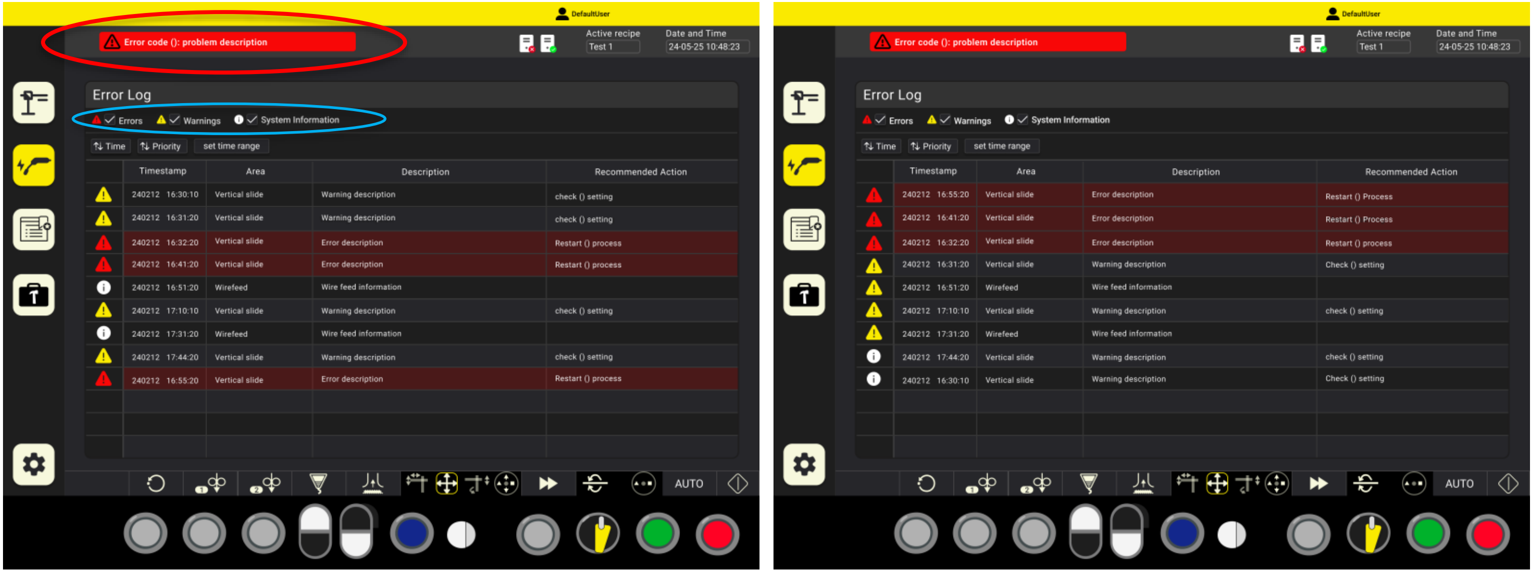

Figure 44: Log with filtering options for sorted by time incoming (left) or priority (right)

The Error Log view can be seen in figure 44, and is always accessible through the top bar, by clicking error log message field (red circle). This field will flash in red whenever an error occurs and will direct the user to the Error Log. Here, the user can see the system errors, warnings or system information in a list view. The user can also filter the list depending on time incoming (left) or by importance (right), as well as using the menu buttons for what they want to see in the list (blue circle).

7.2 Design Guidelines

The following guidelines were based on our interviews, observations and user tests conducted throughout the project, in combination with research and literature gathered from external sources. It is important to clarify that there was a limited number of informants both for interviews and user tests, making the guidelines presented in the following sections might just be true for this specific context. The order of the list does not hold any other meaning than being listed, it is merely for structure and no further underlying meaning.

1. Display critical information clearly in the HMI, and allow real-time monitoring and control to facilitate situational awareness

Put the possible interactions and crucial data defined in a relevant context to enhance the operator's situational awareness, by displaying relevant information of critical parameters such as voltage, current, and speed in logical views to help operators understand the current state of the system.

By leveraging the implications of situational awareness in the context of HMI and human operators there is potential for crucial advantages related to the user experience. Villani et al. (2021) suggest a framework with the aim of solving similar design problems. The authors describe three levels that could be considered, perception, cognition, and interaction. Perception adaptation ensures that data is easily perceived by the user. Through presenting information in a clear and accessible manner it can accommodate to the operators' perceptual capabilities (Villani et al. 2021). Our guideline utilises similar philosophy by decreasing the presented possible interactions and maintaining focus on the elements that are interactable in the current view. Findings from initial interviews are the ground for our perception of important and less valuable information at a specific view.

Figure 45: Displaying relevant information of critical parameters such as voltage, current, and speed in logical views to help operators understand the current state of the system.

As seen in Figure 46, the important parameters have been centred on the view to facilitate situational awareness. Comparing this view to iteration one (see Figure 9) highlights the implementation of this guideline. Regardless of if the machine consists of one or more welding heads, the interface visualises the important parameters and interactive elements in a consistent manner, facilitating the situational awareness.

Secondly Villani et al. (2021) describes cognition adaptation as the aspect of facilitating user's comprehension of the current situation. Meaning that the presented data and information is easy to interpret, allowing operators to easily understand the system's state and the necessary actions. Allow monitoring and visualisation of real-time process data. Ardanza, et al. (2019: p.4046). Similarly, by enhancing situational awareness operators though clear and straightforward interactions are aware of the implications of their actions.

2. Reduce the Operators Cognitive Load by Dividing Unrelated Processes from Each Other

Make the interface intuitive and straightforward, separating unrelated processes from each other to reduce the operator's cognitive load, ensuring that information is easy to find and understand.

As earlier presented in this thesis, cognitive load is the amount of mental effort required to understand information (Opto22 (2014;2021). Complex commands increase the cognitive load, and Villani, V., et.al. (2018) identifies that there exists a complexity of how operators are expected to interact with the robots in a reduced time, and thus hinges on intuitive interfaces, while minimising the risk for user error. With this in mind, the design choice of implying the flow of recipe creation of the interface was used, providing information buttons wherever there could be uncertainty of the functionality. In Iteration One, the process of creating recipes were nestled within other settings, creating confusion and a more complex navigation process. according to their preference.

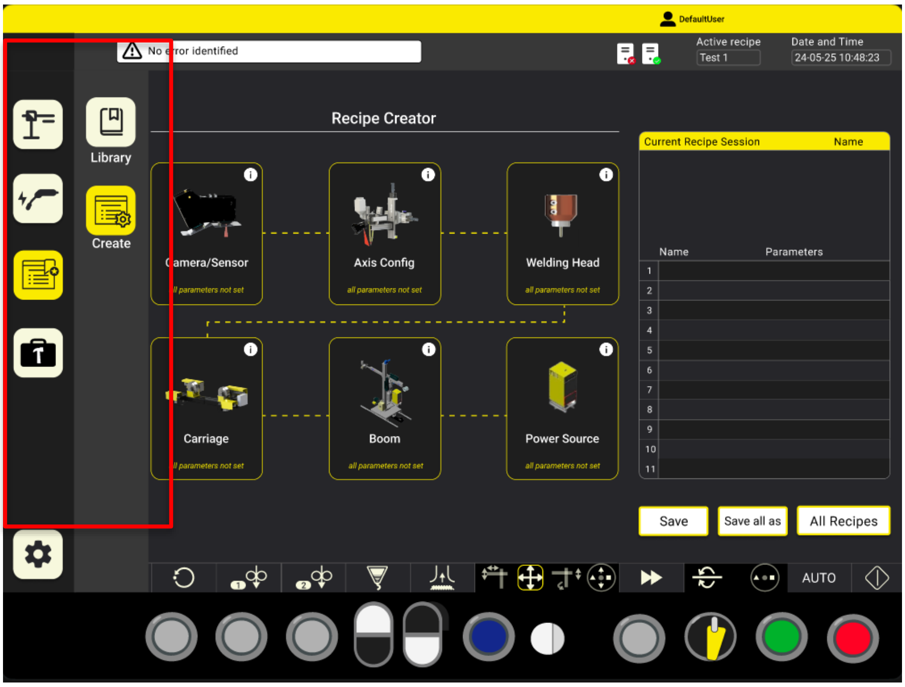

Figure 46: Separating unrelated processes from each other to reduce the operator's cognitive load.

By having recipe creation receive a dedicated view from the menu, the possibility of walkthrough mode, and with modes for either creating an entire recipe, or recipes for each component, the process has been separated from others so operators can more easily utilise the function, and in turn reduce cognitive load.

3. Utilise Information Hierarchy Design Principles to Allow Straightforward Navigation within the HMI

Build an easily navigable information hierarchy that allows operators to quickly access critical information and views, using logical organisation of views and settings in accordance with most-to-least used to facilitate easy navigation.

This guideline stems from the research of nestling and grouping elements in information hierarchies to improve navigation. Opto22 (2014;2021) outlines several methods for grouping; physical proximity, similar shapes, sizes, colours, enclosing boxes, or connective lines, as this enhances the perceptions of connections as well as decluttering the screen.

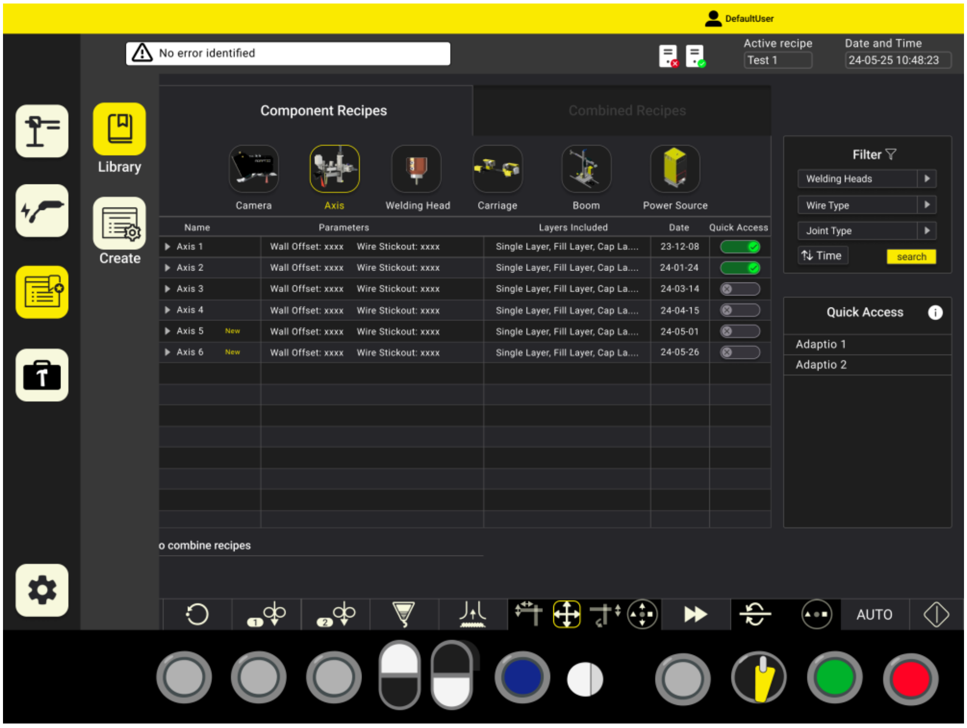

Figure 47: Easily navigable information hierarchy that allows operators to quickly access critical information and views.

In Figure 48, the recipes have been divided depending on type, and can be further filtered through the filtering menu, where this division facilitates using logical organisation of views and settings. While Opto22 (2014;2021) states that an effective HMI should eliminate unnecessary visual elements such as 3D depictions, this was included into the design due to the preference of the informants, both those working as operators as well as informants from user tests. Another aspect is using colour coding as a scheme that reinforces the hierarchy of information, as presented by Watzman & Re. (2007), and has been utilised across all views to utilise information hierarchy design principles.

4. Utilise colours that adheres to the project identity and highlights important features and possibilities of navigation

Design a clear, contrasting colour scheme that adheres to the identity of the stakeholder. Utilise distinguishable colours for different states, ensuring readability and adherence to colour contrast standards.

Watzman & Re (2007) emphasises on the importance of considering colours and contrast in design, such as using colour coding and that colours should work with the project identity or established visual language" (Watzman & Re, 2007).

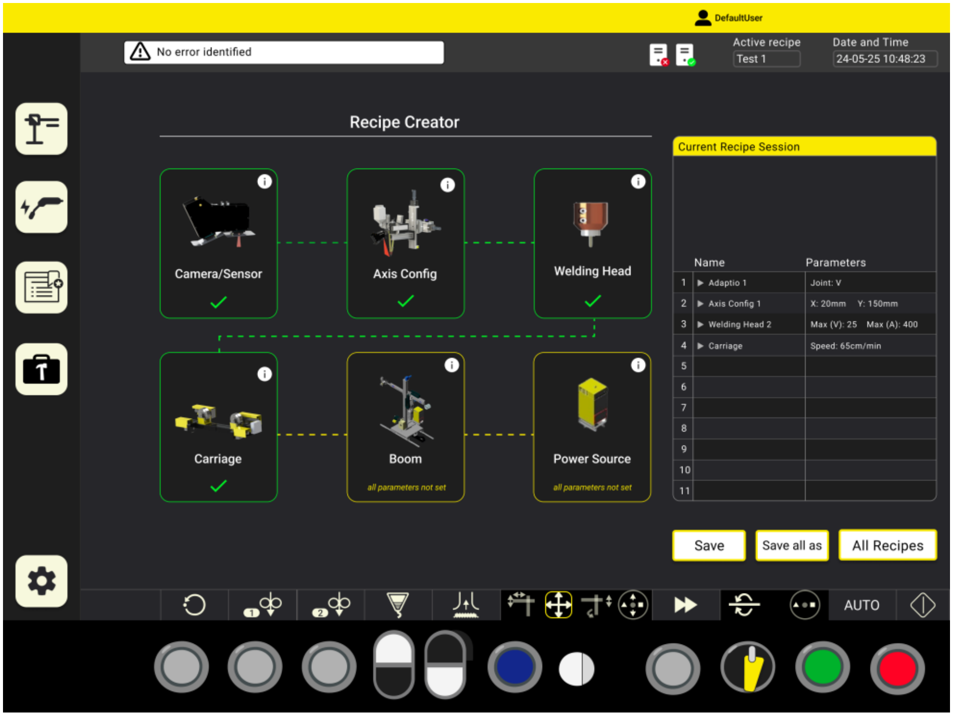

Figure 48: Design a clear, contrasting colour scheme that adheres to the identity of the stakeholder. Utilise distinguishable colours for different states.

The design of the mock-up utilised a colour scheme made by the stakeholder to adhere to the guideline. In Figure 49, this is exemplified through both the use of yellow and green are used to illustrate different states while still adhering to the visual identity. As informants reported a preference for dark mode and dislike of white and yellow due to low contrast, its usage was motivated. The use of black and yellow is also heavily associated with the stakeholder and would therefore meet the requirement of adhering to the stakeholder identity.

5. Put System Statuses in the Focus of Awareness to Improve Error Handling and Feedback in the HMI

Enhance error messages and system feedback with clear error codes and alerts. Offer interactive info texts to help operators diagnose and resolve issues effectively. Provide visual alerts for the HMI in critical situations, such as low flux, low wire, system malfunction, or other issues to ensure operators can address problems timely.

As reported by respondents within the stakeholder, there was a need to improve the error messages and system feedback, with clear error codes and alerts for diagnosing issues effectively. Opto22 (2014;2021) states the importance of highlighting critical information and letting less important data be in the background.

Figure 49: Feedback with clear error codes and alerts. Interactive info texts to help operators diagnose and resolve issues effectively. Visual alerts for the HMI in critical situations.

By utilising a red colour that flashes when an error occurs or low wire, the incident draws attention from the other elements, focusing the awareness of critical situations or important parameters.

6. **Utilise visual icons to convey universal meaning and avoid translation issues**

Utilise icons to visualise information, making it easier for operators to understand the system status and interact with the HMI regardless of experience level or language. Incorporate internationally recognized symbols for user-friendliness.

Opto22 (2014;2021) identifies that familiar commands or icons decrease cognitive load. Di Gregorio et.al. (2020) examined existing industrial interfaces and provided a design guideline for monitoring the state of the machine, as there is a risk to overload the interface. For this problem, they recommend using icons to indicate specifics of the state of the machine.

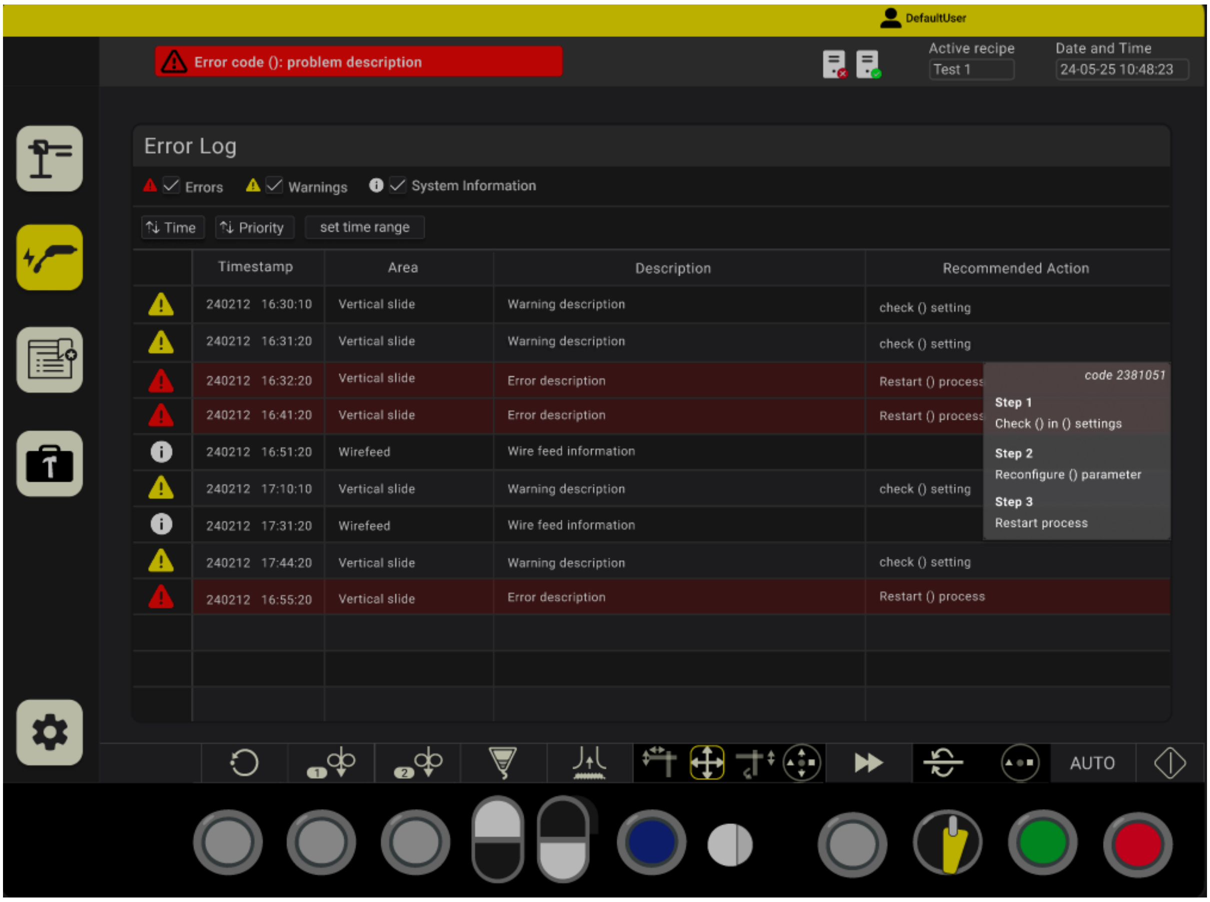

Figure 50: Utilising universal symbols to convey clear meaning of the system status

To draw from the mock-up, the error log seen in Figure 50 uses warning triangles as they are commonly occurring in other contexts, making it easier for operators to understand the information regardless of culture or language. Further, the is interactable to provide more information, such as recommended action steps. Utilising these icons can help conveying meaning in a clear and concise manner, without cluttering the interface with text.

7. Design for permission levels in the system regarding the users experience and use cases

Provide permission options to adapt the interface to different user experience levels, allowing operators to have a personalised experience of the HMI based on their roles and tasks.

As reported are both informants from the interview as well as one user test, working with permissions is important to avoid confusion or user error. As presented by Ardanza, et al. (2019) the overarching goal is to empower operators with customised, adaptable machines that facilitate access to essential information directly from their workstations. This is further supported by Villani et al. (2021), who states that by presenting information in a clear and accessible manner, it can accommodate to the operators' perceptual capabilities.

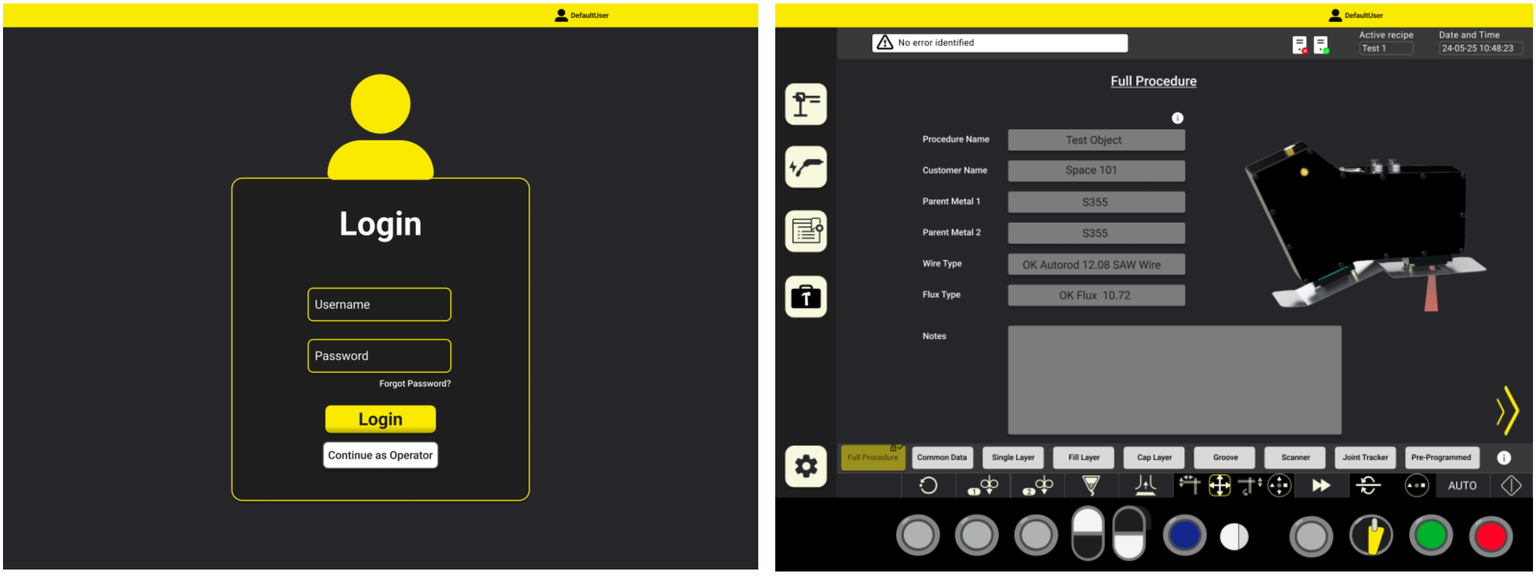

Figure 51: Permission levels depending on Login credentials (left), affecting what they can interact with (right).

To follow such principles, it is important to make some limitations in terms of what the operator can or cannot see, as well as what they can or cannot interact with. As seen in Figure 52, when a user logs in as a operator, they cannot interact with certain parameters such as system settings that are often only set when installing the machine. However, to maintain transparency and not hide elements, the information is still visible, as it might be required for operators to see to further make informed decisions when inputting other parameters. By designing for different permission levels, contents in the HMI can be better adjusted to different use cases and level of experience.

8. Consider all users as potential inexperienced users

Incorporate user guides and information directly within the interface to provide ongoing support. Ensure operators have easy access to information about system status, operations, and troubleshooting.

As highlighted by the informants within the stakeholder company, even experienced welders can have difficulty understanding terminology used. Di Gregorio et.al. (2020) recommend focusing on supporting monitoring industrial production, as in Industry 4.0 as there is an increased complexity when it comes to data processing, as well as a need for operators to understand such data quickly to avoid critical situations (Di Gregorio et.al., 2020).

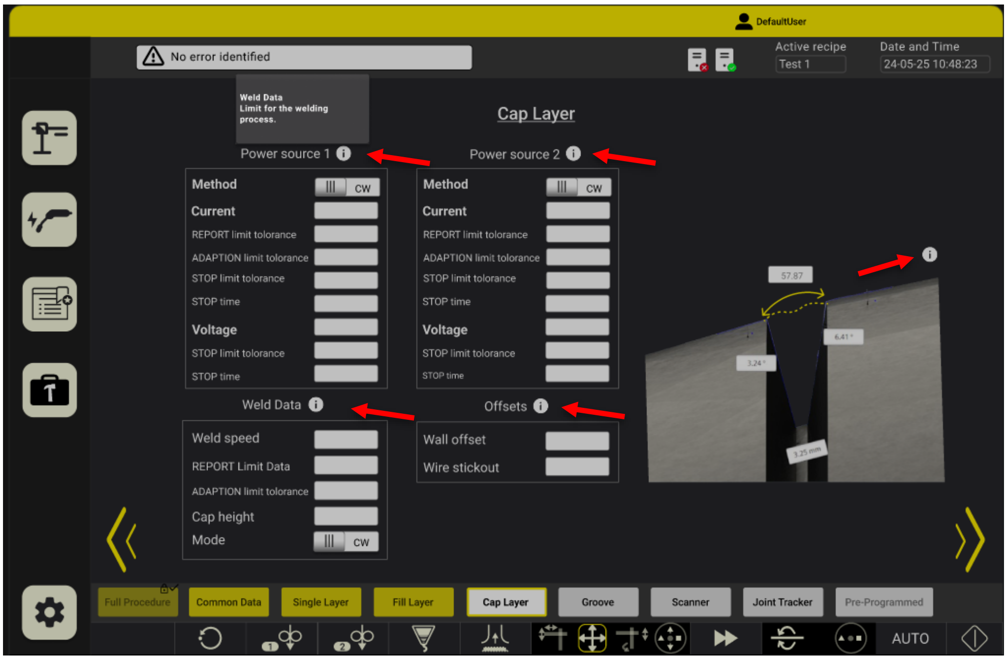

Figure 52: Incorporate user guides and information directly within the interface to provide ongoing support.

By providing user guides and information directly in the interface, the operator can more quickly understand and manage both utilisation of the HMI as well as when errors occur.

As can be seen in previous Figures, all views contain information icons. As can be seen in Figure 53, information icons are provided wherever there can be uncertainties in the interface. By considering all users at potential inexperienced users, more support can be incorporated into the HMI.

8. Discussion

The following chapter contains discussions regarding the results and methods used in this thesis. Further chapters relate to methods that were ultimately discarded, as well as the validity and generalisability of the results, and future work.

8.1 Result Discussion

Before discussing our result, it is important for us to address the identified wicked problems that occurred during this project. Which Ritchey (2013) and Coyne (2005) said is bound to happen in projects, specially design related projects. The first wicked problem which affected the result was the fact that we identified, from interviews and observations, that a lot of the parameters were less important than others, but the scope didn't allow us to spend time on categorizing them. Being able to categorize the parameters from important to less important we would have facilitated developing a specific design guideline applicable to many future design projects within the welding industry. Having a reference map regarding the importance of parameters would enable designers to prioritise crucial elements effectively, streamline the decision-making process, and ensure that the most impactful aspects of the HMI design receive the attention they require. This would lead to more efficient and targeted design efforts, enhancing the overall usability and functionality of welding machine interfaces. This wicked problem had direct impact on the suggestion of the design guideline "Design for permission levels in the system regarding the users experience and use cases." where we suggest that once certain parameters have been identified to be suitable for different operator experience, designers should separate these from each other to facilitate user friendliness and usability for all users.

Similarly, another wicked problem emerged within the same domain. Our inability to fully understand each parameter that could be configured in the system constrained us to adhere closely to the mock-up created by the stakeholder representative. This limitation might have affected our innovation and design solutions, potentially restricting the final design from the start. If we had not been influenced by the existing mock-up, the design guidelines might have been entirely different, allowing for a more flexible and innovative approach.

The final major wicked problem is relevant both to our thesis project and to the industry as it transitions towards Intelligent Welding Systems (IWS) (see Section 2.3). According to Wang et al. (2020), as welding machines become more intelligent and automated, it is assumed that operators will spend less time directly interacting with the welders. However, in reality, the increasing complexity of these machines introduces more parameters and settings for operators to manage, thereby complicating the systems (Wang, B., et al. 2020). Our initial idea was to somehow streamline the information communicated by the system to make it more digestible and user-friendly. Once we identified that it would require more extensive research to be done; to address this wicked problem instead we propose the guideline “Reduce the Operators' Cognitive Load by Dividing Unrelated Processes from Each Other.” As systems become more intelligent, it is crucial to create clear distinctions between different processes to enhance usability and reduce cognitive overload for operators.

By approaching this thesis with a human-centred approach crucial insights and findings have been gathered already early in the project to suggest design guidelines. Also, we note that it has been crucial for developing the HMI of this thesis project. Despite the human-centred approach being a methodology, it is suitable for this thesis to discuss in the result discussion, since by adapting this approach has made the project gather further insights outside of the research question that supports the vision of researchers such as Pacaux-Lemoine et al. (2017) and Trentesaux and Millot (2016), who describes an industrial environment where development move more and more towards techno-centred approaches as machines become more automated. Focusing firstly on implementing and designing for system capabilities and involving humans towards the later stages (see Section 3.2.1). This was discovered when working with this thesis and the stakeholder company as well, where an informant within the stakeholder company reported that the HMIs sometimes felt like an afterthought. Instead, by adopting the human-centred approach throughout the whole project, insights that might be considerably basic and easily identified were a part of our development from the start instead of having these findings appear at later stages of a project, which is what Pacaux-Lemoine et al. (2017) has identified to be a problematic development found in IMS development (see Section 3.2.1). Through this approach we were able to early in the project adhere to Wang et al. (2020) recommendation of incorporating customization and adaptability in the welding systems (see Section 2.3).

From conducting initial interviews, it was discovered that the operators found the current HMI lacking in user-friendliness and flexibility. Specific issues identified included navigation difficulties, unclear hierarchy, and confusing symbols and information displays. Addressing these minor yet impactful problems could significantly improve the overall user experience.
To further validate the insights gathered through the human-centred design approach, we developed a mock-up incorporating these findings and used it during user tests to obtain additional feedback. This iterative process was crucial in determining whether the adjustments made to the overall navigation, hierarchy, symbols, and information presentation were effectively enhancing user-friendliness.

The results from these user tests confirmed that the changes aligned with our goals. Operators reported improved ease of use and greater satisfaction with the new design. These findings support Cooper et al. (2014) assertion that interaction design should streamline workflows and minimize user errors, ultimately enhancing productivity. By iteratively refining the HMI based on user feedback, we were able to create a more intuitive and efficient interface that better meets the needs of the operators.

The design guidelines suggested in this thesis underscore the importance of incorporating human insights and feedback throughout the entire development process to be able to answer what modern user interface design principles should be considered when designing the HMI of industrial welding machines. Just as formative evaluation emphasizes continuous feedback and discussion, involving users early and consistently not only improves learning but also enables developers to identify and address requirements at the initial stages of a project. In fact, when reflecting on the project, the foundation of our design guidelines was established after the initial set of interviews and unofficial meetings. These early interactions provided critical insights that shaped the subsequent development and evaluation phases, ultimately strengthening the reliability and credibility of the guidelines. Which is further strengthened since we were now able to refine the guidelines through multiple rounds of feedback and evaluation. Each phase of the project benefited from the insights gathered in previous stages, allowing for a more nuanced understanding of user needs and system requirements. For instance, early feedback

revealed certain usability issues that were not initially apparent, leading to adjustments that significantly enhanced the user experience.
Moreover, this approach fostered a collaborative environment where stakeholders and users could openly share their perspectives and concerns. This collaboration was instrumental in ensuring that the final design was both practical and aligned with the expectations. With all this in mind, we argue that approaching similar development projects with a human-centered design methodology allows for the creation of design guidelines that facilitate usability and enhance user friendliness. This approach ensures that the end-product is closely aligned with user needs, ultimately leading to higher satisfaction and more effective utilization of the system.

8.2 Method Discussion

This thesis aimed to apply the most relevant methods from interaction design, integrating both qualitative and quantitative methods to ensure the final guideline had a credible foundation. The most utilised methodology throughout the thesis was the Double Diamond design process, as well as utilising Agine Management methods throughout iterations of the HMI mock-up as well as the guidelines. To procure relevant findings from the interviews and user test, thematic analysis was used.

The Double Diamond stages was used to guide the thesis and mock-up development through the four stages; Discover, Define, Develop, and Deliver (The Design Council. n.d.). The structure of these phases provided a clear guide for how to proceed with the initial research, all through to the result presented in this thesis, ensuring each phase was building off previous phases. In the Discover phase, a literature review was conducted to explore current research in the domain of welding, Industry 4.0, HMI design, and more. Interviews were also held to collect baseline data and understand both user needs and challenges with the current design. The Define phase involved integrating this information to define a clearer project goal and design criteria. During the Develop phase, interactive prototyping and user testing was used to refine the HMI mock-up, gathering additional insights from informants. Findings from these three stages were collected in the Deliver phase, containing a finished HMI mock-up, and set of Design Guidelines to improve the usability and facilitate automation of welding machines. Utilising the Double Diamond method felt appropriate due to the distinctiveness of the phases.

The Agile methods, especially the Spiral Methodology, were utilised in the HMI mock-up design to manage the iterations, enhancing both the level of adaptability and flexibility Barry Boehm (1988). The project was divided into several iterations, with periods of assessment and adjustment after feedback and insights gathered from the interviews and user test. Using the iterative nature of agile management was important as it accommodated the complex and expanding requirements of the HMI design. By using an Agile methodology there were incremental improvements throughout the project lifecycle.
Another well utilised method was Thematic Analysis due to the qualitative nature of this thesis. There was a total of fourteen informants from the interviews and user tests, where the thematic analysis was used to code the data to identify themes and patterns of what the informants reported. These themes and patterns helped inform the current state of the HMI design, possibilities for improvements, user experiences, and preferences as well as enhancing the design guidelines. For this thesis, thematic analysis was suitable due to the degree of flexibility it provided, allowing for in-depth analysis of the qualitative data without the rigidity of other data analysis methods (Castleberry & Nolen, 2018; Nowell et al., 2017). Through identifying key themes, the HMI design could be tailored to address user needs and improve the usability of the HMI.

A variety of other methods and frameworks were utilised in this thesis to enhance validity and reliability of the findings. A mixture of Convenience sampling and Purposive sampling were used. In the initial interviews, the informants were selected due to partially being available, and partially to being employed within the stakeholder, thus there was an ease of access which is the definition of Convenience Sampling Etikan et al. (2016). However, these informants had the required experience and knowledge to provide the sought after information, which also falls under Purposive sampling Lopez and Whitehead (2013). For the user tests, informants outside the stakeholder domain were asked to participate. The informants for these sessions were also selected based on convenience, but there were also elements of purposive sampling as they were selected due to their background knowledge of either UX design, working within IT development or had prior welding experience. The user testing and heuristic evaluation helped identify potential usability issues in earlier stages of development, where some elements of participatory design principles could ensure that the end-users participated in the design process, which enhanced both relevance and effectiveness of the HMI design.

These methods helped facilitate a comprehensive and user-centred approach to the HMI mock-up design project and thesis. There were however challenges, such as time constraints, the complexity of integrating new design elements balanced to upholding a consistency with the existing stakeholder requirements and standards. Despite such challenges and limitations, the methods utilised provided enough iterative and flexible capabilities to provide significant improvements to the HMI design, which were reflected in the feedback from the user testing sessions. Utilising the Double Diamond design method, Agile methodologies and analysing the data using thematic analysis, along other qualitative methods, provided a robust framework for creating a more user-centred HMI for semi-automated welding systems. Using iterative methods allowed continuous improvement and ensured the user needs could be more easily aligned, ultimately contributing to a more intuitive interface design.

8.2.1 Discarded Methods

Many aspects of agile methodologies were used, where the nature of a master thesis is akin to the waterfall methodology with a more linear structure of project phases due to outside factors such as stakeholder time limits and deadlines. However, internally the project utilised more of a spiral methodology as it was iterative in nature, adjusting the direction as it progressed while maintaining the overarching goals. In turn, the scrum methodology was not applied.

A Gantt chart was also used to manage the project, goals, and deadlines (Geraldi & Lechter, 2012). While it helped mapping the project in terms of how and when it needed to progress, it was not consistently used. This may be due to the nature of the members of this project, having inter-personal communication frequently which therefore did not demand other tools for time management other than personal calendars. It is therefore recognized that a Gantt chart can be utilised better as a project team increases, ensuring all members have the same perception of what needs to be done, but in smaller teams, the same effect can be applied if communication between members is clear and effective.

While it was initially considered utilising the WOz method for the research, no significant advantages were identified to use it during user tests. Early in the project, when the scope and focus were still undefined, we thought WOz might be necessary to manage the complexity of prototyping the entire system within our timeframe. We considered that manipulating interactions from another connected computer could be a feasible solution. However, once the project scope was clarified, we realized that all required interactions could be effectively prototyped using Figma. Woz is intended to be used when a system is not fully functional or developed, therefore requiring an unseen operator who simulates functions, enabling the testing of user interfaces and interactions as if the system were complete (Dow et al., 2005). As the scope of the thesis never was to develop an HMI that eventually would require functionality, the use of Figma allowed enough intractability to conduct user tests, and no interference of unseen operators.

We chose not to use triangulation in our research, focusing instead on gathering qualitative data. Triangulation should be used with care, and when researchers can motivate that the combination of qualitative and quantitative data could provide clear value (see Section 4.10). Our goal was to understand user experiences and challenges with the existing HMI in welding systems, and qualitative methods provided the in-depth insights needed to explore user interactions and preferences Lopez and Whitehead (2013). We argue that Quantitative data would not have offered the same depth of understanding for our specific focus. While statistical analyses are useful, they might have missed the insights of user experience critical to our study. Our research question required a detailed and nuanced understanding of user interactions to identify design principles that improve usability and facilitate automation. Also, incorporating quantitative methods would have increased complexity and resource requirements, which were beyond our thesis scope. We believed that detailed, nuanced data from qualitative methods would be sufficient to develop and iterate our design guidelines.

8.3 Validity and Generalisability

Despite our findings are catered towards the context of welding systems, we argue that the principles and guidelines presented can be generalized to other industrial HMIs. The core principles such as customization, intuitive navigation, clear communication, and reducing cognitive workload, are applicable to various automated systems beyond welding.

Due to the qualitative nature of this thesis, the result cannot be completely validated or generalised. To ensure reliability, more user tests would be needed to control whether the results from this thesis would provide the same results in other environments, with other users or in other applications (Bell, 2015). The first iteration of guidelines (Table 4) is relatively broad, and therefore has application possibilities in other domains, however, more research would be required to evaluate the usefulness of them. As for the final guidelines, they are domain-specific and whether they can be utilised in other industrial settings would require further research as well. Specific design solutions and guidelines might require adaptation to fit different contexts. For example, while the focus of reducing cognitive workload and improving the overall user experience is universal, the implementation details might vary on specific use cases. To ensure a wider applicability, future work should focus on testing these design guidelines in different settings and with different automated systems. Which in our opinion would help validate the generalisability of our findings and refine the guidelines have a broader applicability. An identified limitation would be the relatively small sample size and the focus on one type of welding machine. This is also something that limits the generalizability of the findings to other contexts.

For validity, some considerations were made for interviews and user tests, trying to not ask leading questions and asking follow-up questions to informants to ensure there was a mutual understanding of the points they brought up. Further, by iterating the design of the HMI mock-up as well as the design guidelines, we could ensure both were aligned with both real-world usage as well as to the user needs. Each iteration refined the design, which in turn also helped making the guidelines concrete to their use cases. Moreover, by involving informants from the stakeholder company throughout the development process ensured both the mock-up and design adhered to the practical requirements of the actual system.

To summarise our view on this topic, while our study provides valuable insights into improving the HMIs for automated welding systems, we suggest that additional studies and broader testing should be conducted before these guidelines can be effectively applied across different applications. Therefore, future work should expand the sample size, with a more diverse user group and testing the guidelines in various settings to enhance the generalizability.

8.5 Future Work

First, some future work for our final mock-up is required to further validate its usability. This should focus on extensive user testing with a more diverse range of operators, these tests should incorporate more advanced features like maintenance alerts, real-time analytics and manual parameter input will enhance functionality and provide additional valuable insights. Further refinement of visual elements and interactive components based on feedback is required to maintain an intuitive interface. As discussed, this mock-up only covers parts of the systems capabilities, to conduct user tests with a mock-up covering all aspects would provide valuable insights to further iterate on our design guidelines.

The results of the study suggest that integrating user feedback into the design process significantly enhances the usability and efficiency of the HMI. The thematic analysis of interviews and user tests provided a deeper understanding of user needs and preferences, which informed the final design guidelines. Future work should focus on further refining these guidelines and conducting more extensive user testing with a broader range of informants with relevant background, such as welding experience, HMI design experience, or user interface design experience. Such work would also further strengthen the validity and reliability of the results presented in this thesis. Additionally, exploring the integration of advanced technologies such as AI and machine learning could further enhance the adaptability and intelligence of welding systems.

9. Ethical Considerations

Research ethics has been a part of research for a long time but has previously been more informal compared to today (Bell, 2015). Patel and Davidson (2019) say that there needs to be a balance between the benefits that research brings to society and protection against inappropriate transparency in, for example, individuals' private lives. In the study confidentiality has been considered. Sensitive information such as name and age has not emerged from the interviews, instead the informant’s job title will be used to describe them. Confidentiality should be a promise that a person will not be able to be identified or be described in such a way that one can be identified (Bell, 2015). Therefore, the decision to include the informants' job titles our confidentiality is limited, since these job titles separate the informants from each other. Bell (2015) says that there can be difficulties promising full confidentiality for the informants, this applies to this study since there was a need to mention the informants job titles to give background to the study’s information gathering. When gathering empirical material, the ethical aspects are important to have in consideration (Bell 2019). Furthermore, Patel and Davidson (2019) mention that essay work should include careful consideration of the ethical aspects.

9.1 Limitations

For this thesis, there were some limitations that must be addressed. One of the earliest limitations was the domain of which this thesis is in. Industrial welding systems are becoming more complex (Villani et al., 2018); Wang et al., 2020); and without prior education or knowledge about welding or common systems used for welding, there was a knowledge barrier that limited the amount of understanding of the HMI itself. Because of this, an earlier mock-up of the HMI provided by the stakeholder had to be used for referencing, such as what settings or parameters to include, and the larger architecture of the interface, as making alterations of this would require a much deeper understanding of welding. This is something that results in other design related limitations, getting exposed to the stakeholders HMI under development probably have impacted how we developed our HMI suggestion. Making it difficult to take design decisions that are not in some way influenced by that HMI.

Another limitation was the time constraint, as the work for this thesis started later than intended due to prior commitments. The workload had to therefore be increased to fulfil the requirements of this thesis. Further, this affected the sample size of informants. It was originally intended to conduct user tests and interview with customers of the stakeholder to find insights that have not been identified by the stakeholder.

While this thesis primarily focused on improving the usability and automation of HMI in welding systems, it does not address the sustainability of different welding processes. The study by Saad et.al. (2021) introduces a multi-dimensional sustainability assessment framework that can evaluate welding approaches based on environmental, economic, social, and physical performance indicators. Their findings indicate that a Friction Stir Welding (FSW) process is the most sustainable welding process among those studied, outperforming Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW), and Shielded Metal Arc Welding (SMAW). Although sustainability is crucial for the welding industry, it falls outside the scope of our research. Future work could incorporate sustainability assessments related to Submerged Arc Welding (SAW) to provide a more broader evaluation of welding system improvements.

Lastly, the hardware to be used for the HMI has already been developed, thus limiting the ability for the mock-up created for this thesis to deviate from the hardware constraints, such as physical buttons or screen dimensions. As the mock-up was created in Figma, the interface type that was used was an iPad to simulate the dimensions as closely as possible. While this was sufficient for the scope of the thesis, being able to use exact dimensions and evaluate the mock-up within the hardware itself would more accurately evaluate suitability of the overall mock-up design.

9.2 Sampling Considerations

For the data gathering in this paper, a combination of convenience sampling and purposive sampling were used (See section 4.4.1). As this thesis is aimed at improving an HMI for industry welders but needed to incorporate design principles stemming from other domains, the combination provided a more encompassing perspective. Since the design is intended for use by the stakeholder, having seven informants from within the company was both convenient and relevant. For sampling outside the stakeholder domain, participants were selected based on their prior experience and knowledge in UX design, web design, and the IT industry to gain additional insights. As both the informants for interviews and user tests had the right knowledge criteria and were convenient in terms of accessibility, it cannot be either convenience sampling or purposive sampling, rather both. However, the number of informants meant the contributions of this thesis cannot not state any quantitative conclusions in terms of the reliability of the data. The user group is relatively small, and the HMI serves a specific use case with a relatively small user group.

9.3 Accessibility

As the HMI will be accessed throughout various stages of the wedding process and by diverse users, the contributions of this thesis should accommodate such diversity, considering varying levels of experience and physical abilities, as it is an ethical imperative to ensure the interface is accessible to all potential users. The qualitative nature of this study creates limitations in terms of testing if this thesis achieves such requirements, however, the aim of this thesis has taken accessibility requirements into consideration throughout the process, and delivered design guidelines that can be applicable to more domains related but not limited to welding. Further, the interviews and user tests created an opportunity for experienced and unfamiliar users to provide feedback, which in turn made the design guidelines and mock-up design incorporate perspectives that can make HMIs more accessible for more users.

Accessibility in HMIs is important for usability for diverse user groups, including those from different cultural backgrounds. A study conducted by Khan and Williams (2014) emphasises the significant impact of cultural differences on the usability of HMIs. By analysing user interactions from India and the United Kingdom, the research illustrates how cultural factors affect user experience and accessibility. Using Hofstede's cultural dimensions, Khan and Williams found that cultural differences influence how users interact with and perceive HMIs. Participants from the United Kingdom generally found the HMIs easier to use and more satisfying, while Indian participants encountered more challenges and took longer to complete tasks. These findings highlight the need to consider cultural factors in HMI design to enhance accessibility for a global audience.

Incorporating cultural considerations into the design process can significantly improve HMI accessibility and usability. Tailoring interfaces to accommodate cultural preferences and behaviours enhances user experience and makes HMIs more accessible to diverse users. The research by Khan and Williams underscores the importance of cultural adaptability in HMI design. As our thesis aimed to improve the usability and automation of welding machine HMIs, it is crucial to incorporate cultural factors to develop more inclusive and user-friendly interfaces. While the timeframe for this thesis did not allow us to study further how the developed HMI mock-up would perform over different cultures, it would be an important and interesting angle for future work.

9.4 User Safety

As there is a transition from manual operations to more automated processes, the industry demands a centrality of human factors in production systems (Nguyen Ngoc et al., 2022; Trentesaux and Millot, 2016). This shift is what makes up the industry 4.0 concept, and with the increasing reliance on automated processes within industries, user safety can often become overlooked in the rush to implement new systems. Since this thesis explores the redesign of the interface for automated welding machines and not robotics within industries, it is still crucial to incorporate similar user safety requirements in further development. In the aspect of this thesis, the suggested design must ensure that changes do not compromise existing safety features within the welding machines system. This meant that little alterations could be made to the contents of the HMI mock-up, as knowing what could be simplified or eliminated in terms of settings or parameters would require a more extensive knowledge of welding and technological capabilities and limitations of the hardware and system, which lied outside the scope of this thesis.

9. 5 Informed Consent and Transparency

Finally, it is necessary to obtain informed consent from participants involved in observations, interviews, or user tests by clarifying the purpose of their participation and being transparent regarding how such material will be used in this thesis. For both interviews and user tests, the informants had received information about the project, the purpose of their participation and information of how their contributions will be utilised in the thesis (see Appendix A&B). Further, after receiving this information, the informants were asked if the session could be recorded for data gathering purposes, and where the informant needed to consent before the recording began. Thus, this thesis can ensure that all contributions followed the ethical principles regarding informed consent and transparency.

10. Conclusion

The aim of this thesis was to answer the research question "What modern user interface design principles should be considered when designing the Human-machine interface (HMI) of industrial welding machines?" Through evaluating the current state of interaction design in the stakeholders welding machines, it was possible to identify the usability level- and challenges in the existing HMI of the welding machines through conducting interviews with experienced operators as well as informants with industry knowledge. Through developing mock-ups that draw from the insights and considerations acquired during the initial interviews to conduct user testing, design guidelines viable solutions and overall recommendations were created to enhance the desired user experience and facilitate future automatization. This also involved evaluating how current wielding tool interfaces can benefit from being remodelled with the user experience in mind, with a particular focus on human-centred design. Findings indicated that for less experienced welders, the complexity of an interface can be a significant barrier to learning and adoption. As Interaction design should create intuitive interfaces that lower the learning curve and encourage users to explore and use advanced features, this was something the design guidelines could help facilitate. This resulted in eight design guidelines presented below:

1. Display critical information clearly in the HMI and allow real-time monitoring and control to facilitate situational awareness.
2. Reduce the Operators Cognitive Load by Dividing Unrelated Processes from Each Other
3. Utilise Information Hierarchy Design Principles to Allow Straightforward Navigation within the HMI
4. Utilise colours that adheres to the project identity and highlights important features and possibilities of navigation.
5. Put System Statuses in the Focus of Awareness to Improve Error Handling and Feedback in the HMI
6. Utilise visual icons to convey universal meaning and avoid translation issues.
7. Design for permission levels in the system regarding the users experience and use cases.
8. Consider all users as potential inexperienced users.

While our guidelines provide a solid foundation for improving the HMI of welding machines, further work is needed to fully validate and refine these principles. Future research should involve more extensive user testing with a broader range of informants, including those with diverse backgrounds in welding and HMI design. Additionally, integrating these guidelines into fully functional HMI prototypes and evaluating their performance in real-world settings will be crucial for confirming their effectiveness and reliability.

In conclusion, our research demonstrates that by adopting a human-centred design approach, it was possible to develop design guidelines that offers the potential to enhance the usability and user-friendliness of welding machine HMIs. These guidelines represent a crucial step toward facilitating the automation of welding processes and improving the overall user experience in the welding industry. However, continuous refinement and validation are essential to ensure their applicability and effectiveness in diverse industrial contexts.

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12. Appendixes

Protocol Focus Groups

The focus groups were conducted in Swedish; therefore, it will be presented in its original format.

Appendix A

- Hälsa välkommen och tacka för deltagande. Presentera vad vi gör för uppdragsgivaren och oss själva. Samt hur deras bidrag kommer hanteras. Informera deltagarna om att intervjuvn kommer spelas in, för vilket syfte och hur länge inspelningen sparas. Förtydliga om anonymitet.

1. Kan du börja lite enkelt och berätta lite om er erfarenhet med svetsning och hur många år ni har varit verksamma inom området?
2. Hur var det för er att lära er systemet och gränssnittet för svetsen? Vad för faktorer påverkade beroende på upplevelsen?
3. Om du tänker tillbaka på senaste tillfället du använde svetsen, var det något som du upplevde inte fungerade som du ville?
4. När ni ska konfigurera svetsen inför att svetsjobb ställer ni in inställningarna manuellt eller föredrar ni att använda recept? Vad är anledningen?
5. När svetsningen är igång vad är det viktigaste för er att ha översyn på?
6. Hur upplever ni det är att navigera mellan de olika vyerna av HMI:t?
7. Är det någon eller några vyer i nuvarande HMI:t som är felplacerade i er mening?
8. Spelar det någon roll för va typ av svettsning som ska genomföras för vad ni vill att systemet kommunicerar till er?
9. Öppna frågor (Första delen)
    - Nu när ni har chansen att påverka, är det något ni hade behövt implementera i HMI för att underlätta eran arbetsprocess.
    - Vad är det ni tycker fungerar med det nuvarande HMI:t som ni uppskattar?
    - Hur skulle den optimala feedbacken se ut för att ni skulle känna er bekväma med att gå ifrån svetsningen när den är igång?

Presentation av första mockupen:

1. Vad är er initiala intryck för gränssnittet?
2. Är det några symboler som väcker funderingar eller oklarheter?
3. Är det tydligt hur man navigerar i systemet?
4. Ser ni någon problematik med placeringen av interaktiva element i vyerna?
5. Hur upplever ni färgerna och kontrasterna i vyerna?
6. Är det något ytterligare ni vill tilläga i relation till dessa vyer ni sett? Funderingar och/eller positiva saker?

Appendix B

Pre-Study Findings

These are the noted thoughts and conclusions following the interviews and first visitation to the factory. These findings are a combined result of the interviews from the thematic analysis as well as overall observations.

- Indications on a difficulty in understanding and navigating the current HMI. Especially for new users.
- A need for the interface to be adaptable depending on the uses needs and experience.
- Too feel more comfortable with the overall process operators would want improved error messages and feedback.
- Suggestions for combining sound and light alerts for better notification of errors.
- Concerns expressed about the visual layout, contrast and colour use.
- Preference for clear, contrasting colour schemes, including dark mode for better readability.
- Importance of internationally recognized symbols for user-friendliness across regions.
- Need for readily accessible information about system status and operations.
- Focus on improvements to the real-time monitoring of crucial parameters like voltage, current, and speed.

- Suggestions for interactive info texts and visual dashboards to provide comprehensive information.
- Challenges with the current recipe management system. Is rarely utilised.
- Suggestions for implementing different access levels based on user roles to prevent accidental changes.
- Desire for quick manual adjustments alongside automated settings for broader control.
- Implied need for training and ongoing support integrated into the HMI interface.
- Suggestions for user guides or explanations accessible within the interface.
- Need for real-time monitoring of critical parameters.
- Suggestions for alerts for low supplies like wire or flux to prevent interruptions in welding.
- Desire for centralising essential welding parameters on a main view.
- Suggestions for minimal, logically organised views to facilitate ease of navigation during welding.
- Desire for graphical views of weld seams and layer information.
- Importance of visualising progress and understanding remaining layers for clarity during welding.
- Careful use of pure text, to decrease changes between translation of languages. Utilise icons to communicate information as much as possible.
- Focus on developing HMI that cater existing users instead of improving the experience for new users.
- Very limited feedback from customers regarding the HMI. Does not really know their opinion. So, to continue cater for their experience might be problematic since they are unaware of their opinion.

Appendix C

Protocol User Tests

These tests were also conducted in Swedish so we will present the structure in its original format. During these tests observations was crucial, more so than what they answered on the questions.

- Hälsa välkommen och tacka för deltagandet. Informera om deras roll för projektet.
- Informera om oss och vårat project.

- Förklara hur användartestet kommer utföras.
    1. Vi kommer genom detta användartest be er utföra visa uppgifter, vi kommer notera hur väl ni genomför dessa.
    2. Ni får alltid ställa frågor och beskriva era osäkerheter, då de hjälper oss lika mycket om inte mer än att ni klarar uppgifterna.
    3. Vi värderar inte hur ni väl ni genomför uppgifterna, vi värderar hur väl gränssnittet stödjer er för att lyckas.

Uppgift 1: Först vill vi att du först ökar värdet på Voltage för att sedan minska värdet på Ampere.

Frågor i relation till uppgiften:

4. Vad gjorde att du förstod hur du skulle gå tillväga för att genomföra detta?
5. Var det något som du tyckte var otydligt som hade kunnat göra din uppgift tydligare?

Uppgift 2: Kan du navigera till recept hantering?

6. Förstod du direkt hur du skulle hitta det eller testade du dig fram?
7. Vart skulle du nu klicka för att ta dig tillbaka till där vi var innan?
8. Om du kollar på denna vyn förstår du vart du ska klicka för att ställa in parametrar för den första delen i processen?

Uppgift 3: Nu vill vi att du skapar ett recept för kameran, och går igenom hela den processen.

9. Hade du behövt något från gränssnittet för att göra det tydligare eller förstod du vad som behövdes göras?
10. Hur många steg har du kvar att genomföra för att göra klart alla steg i kameran?
11. Varför använde du eller inte använde du informations bubblorna placerade ut igenom processen?

Uppgift 4: Slutför nu alla recept för resten av delarna.

12. Kan du se på vyn var recepten har hamnat du precis skapat?
13. Är det tydligt för dig hur man får fram information om recepten du har skapat?

14. Nu när du skapat recept för alla delar av maskinen, har du några invändningar, potentiella förbättringar eller allmänna åsikter om processen?

Uppgift 5: Nu vill vi att du lägger till ett recept för varje del i ”Quick Recipe”, när du gör det försök att se information om receptet innan du vill lägga till det.

15. Var det tydligt hur du skulle göra för att klara uppgiften?
16. Kan du försöka filtrerar till recept som är skapade för två svetshuvuden?
17. Vet du vad som kommer hända när du valt alla quick recipes och klickar på ”Play” om du är osäker, vad tror du kommer hända?

Uppgift 6: Ett tidsinställt error meddelande kommer varna användaren om ett error. Här är uppgiften att se hur användaren reagerar utan att informera dem att det är en uppgift.

18. Vad ville systemet kommunicera till dig?
19. Kan du ta och försöka filterara så du får det viktigaste error meddelandet högst upp i listan?
20. Om du bara vill se varningar eller system status vart klickar du då?

Avslutande öppna frågor:

21. Din chans nu att föreslå design förbättringar som hade fått dig att få en bättre upplevelse?
22. Vad var din upplevelse av färgtemat?
23. Kände du att processen överlag var hanterbar, var det någonstans du kände dig lite överstimulerad och osäker på vad som krävdes av dig?
24. Var det tydligt vart du var i processen, och hur du skulle navigera till olika vyer?

Appendix D

Thematic analysis

The following contains thematic analyses not utilized in the thesis but served as a starting point for identifying themes.

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