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Framework and practical guidelines for creating a current state analysis for (re)designing an HMI within the Industry 4.0 era. Case study

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With the wider introduction of Industry 4.0 technologies in the manufacturing sector, a need for methodologies for their integration within organizations is observed. It is noted the success of a solution depends on the appropriate consideration of all relevant factors at the beginning stages of a new project. This thesis examines these factors for the human-machine interface (HMI) development through academic research and later proposes a new framework with practical guidelines. The framework combines the human factors, organizational aspects, and values, operational and manufacturing processes, and technologies. As the focus of the framework is human-machine interfaces practical human-centred methodologies for a systematic research phase are supplemented. The validity of the framework is tested in a case study for an HMI redesign in a Dutch machine manufacturing company. The evaluated findings highlight the value of the framework, but also point to some gaps and call for further research.

Human-machine interaction; Human-centred design; Digital transformation; Industry 4.0

1. Introduction

This chapter presents the background information, the aim of the thesis, and its objectives. The research question is formulated and the delamination is stated.

1.1 Background Information

Industry 4.0

Industry 4.0 (I4.0) aims to create the integration of different technologies for a more autonomous and self-regulating production system [1]. This ideology extends over all parts of an organization- business, people, technology, and the supply chain and therefore the transition to Industry 4.0 introduces technical, organizational, and human-related changes through the different organizational layers [2][3]. While every aspect of an organization can be Industry 4.0 compliant, having only one is not possible, as integrating I4.0-related technologies needs to happen on all organizational levels and aspects, as seen in figure 1 [4]. Even though I4.0 is touted as automation and digitalization driven, workers will remain essential for manufacturers, especially for complex and high-tech industries [5].

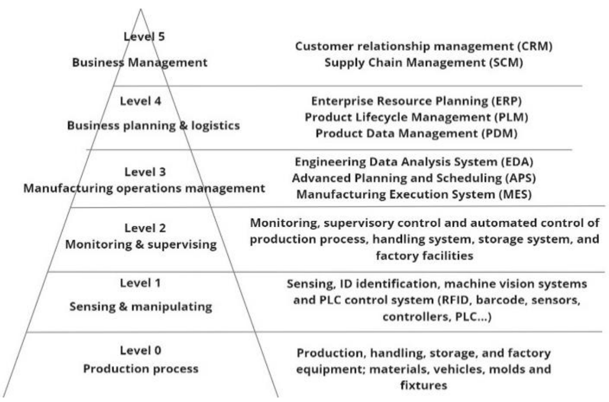


Figure 1. The levels of manufacturing control system [4]

There are many technologies associated with Industry 4.0, however in a paper by Dalmarco et al. [1] nine are recognized as the most discussed in literature. They are shown in Table 1, with their given definitions.

Technology	Description
Simulation	Allows the virtualization of product design, processes and factory layout. Simulation tools allow testing virtual models of products or processes before applying it into real solutions, optimizing the development of new technologies.
Big Data and Analytics	Set of technologies and tools capable of processing and analysing large volumes of data that are: generated continuously; composed of texts, images, etc.; and from multiple departments. The analysis of such data may help to identifying existing failures in detail, increasing the available knowledge about consumers habits and preferences, among others.
Cloud Computing	Services that provide access of machines, systems, software and tools through networks like the internet. It replaces the necessity of acquiring products, know-how and/or costly infrastructures.
Cyber-Physical System	Integration of collaborative physical computational entities (machines, robots, sensors, etc.) that interact through a virtual network. It includes smart machines, storage systems and production facilities that can exchange information with autonomy and intelligence, are able to decide and trigger actions, and can control each other independently
Cybersecurity	Services and technologies with the aim of protecting users, systems, equipment,

	networks and industrial data of illicit intrusion.
Collaborative Robotics	Robots (mobile and/or fixed) that operate in automate physical processes and interact with human operators or other robots in an intuitive self-learning behaviour.
Augmented Reality	Integration of virtual information with the real world through the combination of 3D elements with the spatial context of the factory. It allows an interactivity and real-time processing of image projection, being used either to improve the manufacturing process or to test new products.
Additive Manufacturing	Technology that allows printing objects by composing layers of plastic or metal, avoiding the waste of material in processes such as cutting. Used initially for producing prototypes or small series of complex parts, it is now being used for large scale production.
Systems Integration	Integration of data at all levels (from management to shop floor) of a company and between (from suppliers to customers) companies in the supply chain according to their data transfer patterns. Usually connected through Internet of Things applications.

Table 1. Definitions of technologies related to Industry 4.0 [1]

Human machine interfaces

A Human-machine interface (HMI) is part of industrial control systems (ICS) and is defined as a control panel through which a manufacturing machine is partly or fully operated by a human. It provides the necessary information about the given manufacturing process, helping the operators to carry out tasks within the physical, virtual and simulated system. Therefore, the design and usability of the HMI directly influence the overall equipment efficiency (OEE) of the machine, the manufacturing operations, and the interdependent relations between the HTO (human, technological and organizational) factors [6]. As the design of the HMI is bound to the production processes, the increasing complexity and amount of adjustable variables in current machines are reflected in the usability of the HMIs, especially for the main users- operators [7]. According to Åkerman [8] the shop floor IT, part of which are HMIs, are production systems and should support both the human and the technical aspects like future manufacturing and assembly systems and organizational functions like maintenance and logistics. The integration of I4.0 ideologies in companies is pushing HMIs in new directions. One of them is platforms that adjust and cater according to the users at all levels of the manufacturing control system, like operators, supervisors, quality and production managers, and continuous improvement engineers. Another one is implementing I4.0 technologies like augmented and virtual reality to aid the operators in their work, creating what is known in literature as Operator 4.0 [9]. The new role of the human as a decision-maker should be in synergy with the manufacturing environment and supported through their tasks, interactions with the digital support system, and adapted to their cognitive abilities [6].

Research gap

In academic literature it is well-recognized that the successful integration of new developments in Industry 4.0 largely depends on the compatibility between technological support and the human factors, calling for new human-centric design and engineering philosophies within the field. Many papers talk about adoption of human-centred manufacturing within Industry 4.0 and emphasize the importance of interoperability not only between software systems but also between people and organizational structures [6][10-13]. Currently, RAMI4.0 and the TOE framework are one of the most popular and frequently used models for developing and integrating Industry 4.0 technologies and have been used in five different paper for technological developments [14-18]. However, in more recent academia both are criticized for their lack the user-centric views and for requiring additional human-focused frameworks [16] [18] [19]. Kadir and Broberg [7] and Neumann et al. [20] have done systematic reviews of the academic papers related to human factors and Industry 4.0, to conclude that the research is scarce. Moreover, in the review paper by Cañas et al. [21] on implementing Industry 4.0 principles, out of the seven analysed Industry 4.0 conceptual frameworks only one contained the human factor as a principle. It also had the least amount of total citations- 15, which is 0.8% of the total citations from the seven papers. Kadir and Broberg [7] further point out the increasing number of academic publications which call for further research focused on developing new frameworks and guidelines aiming to assist practitioners in adopting human-centred design in their Industry 4.0 enabling technologies. While multiple frameworks for developing or redesigning technological solutions within the I4.0 era and considering the human factor exist they all call for further research on practice-oriented guidelines and tools on how to use the frameworks in industrial settings [7] [20] [22-24]. The existing frameworks only investigate what should be considered during development, but not how.

1.2. Aim of the thesis

The implementation of Industry 4.0 solutions requires the cooperation between humans and technology in the environment of an organization, therefore their design should consider these three aspects. They are especially important for HMIs, as the machine's operability depends on the correct interaction between the HTO factors. Thus for the successful development of HMI in the I4.0 era, an understanding of the existing state of an organization is needed. Although a current state analysis is part of multiple I4.0 implementation frameworks, they call for future research on practice-oriented guidelines.

This thesis proposes a new framework supplemented with research methodologies and guidelines. It will be based on existing works and academia and its scope will be limited to the research phase of the development cycle. The goal of the framework is to assist and guide decision-makers in creating a holistic and comprehensive view of the relevant aspects of developing an HMI. The additional proposed methods for acquiring the information are focused on user-centric design and systematic research and documentation, which can aid organizations in applying the framework in real life.

1.3 Delimitation

The scope of the proposed framework has three dimensions- the object of focus, the limits of the chosen development section, and the selected environment application. The object is an HMI, where the taken definition is- an interface that connects people to a system in the context of industrial manufacturing transitioning towards Industry 4.0. The framework is concerned with the engineering design process, which although considered highly iterative and having various articulations ultimately includes a research phase. The goal of this phase is to locate and research the existing current state to better understand the factors associated with a pre-defined problem. Relating to the goal of the framework and the background information, it is evident that for the successful development of a new HMI solution, a complete overview of the existing state of the relevant factors is needed. Without doing so, the responsible entities cannot make adequate design decisions. Therefore, the framework will be limited to the research phase of the development cycle and will not be discussing the requirements formulation.

1.4 Outline of the thesis

1. Introduction: The introductory chapter present the research area, research gap, the aim of the thesis, its delimitations as well as this outline.
2. Methodology: Describes the chosen research approach and methods used.
3. Theoretical framework: The theory chapter consists of three parts. The first part describes the relevant academic literature. The second part goes into the existing frameworks. The third part is the requirements for the framework based on the theory.
4. Framework: Description of how the framework was created, followed by its detailed explaining and how it can be applied.
5. Case study: Provides background information about the case study company, followed by how the framework has been applied.
6. Evaluation of framework: Discusses the case study results, followed by an evaluation of the results and the framework requirements. Lastly recommendations and further research is given.
7. Discussion and Conclusions: Concluding remarks of the thesis, including the theoretical contribution, and limitations.

2. Methodology

This chapter describes the research approach, design, and the methods used. The research approach is based on the research goal of the thesis found in the introduction chapter.

2.1 Research approach

The research approach should be based on the nature of the research problem and will influence the research design, procedures, and specific methods of inquiry [25]. The research problem presented in the thesis has a practical nature, which follows the applied research paradigm. As opposed to basic research, it is used for solving practical problems [26]. The chosen approach for this topic should connect to the research paradigms from both social sciences and production engineering fields. An established approach that has these two aspects embedded in it and is used for designing and evaluating information systems (IS) is design science [27]. Therefore, it will be used in this thesis.

2.2 Design science research

Design science is a paradigm that separates the science of artificial from natural science, as the artefact depends on the goal of the designer. It is defined by Hevner and Chatterjee [27] as "design science research is a research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body of scientific evidence. The designed artefacts are both useful and fundamental to understanding that problem." In their work they apply the design science methodology in the domain of information systems, resulting in a six-step framework and guidelines, originating from IS. The guidelines seen in Table 2 will serve as a base for the outline of this thesis.

Activity	Description
1.Problem identification and motivation	Define the problem and justify why it needs a solution. The justification happens with motivation and acceptance of the results.
2. Define the objectives for a solution	The goals (requirements) of what the artefact should accomplish, which could be explained qualitatively or quantitatively.
3. Design and development	This is where the researcher creates the artefact, which could be constructs, models, methods, or instantiations (applications).
4. Demonstration	Demonstrate that the artefact solves the defined problem in one or more ways. This activity can involve empirical methods like experiments, simulations, case studies etc. or logical proof.
5. Evaluation	In the evaluation step, the artefacts ability to solve the problem is measured and evaluated. Like with a demonstration, this activity can be done with any appropriate empirical method or logical proof.
6.Communication	Disseminate the problem, solution, and evaluation results to relevant audiences.

Table 2. Design Science Research Methodology [27]

IS systems and their organizations are composed of people, structures, technologies, and work systems [28]. The interplay between these factors is becoming even more significant with the progression of Industry 4.0, as technologies are currently seen as enablers of business strategies and organizational structures. As derived from the design science definition- design is seen as both a process (activities) and a product (artefact), where the design processes create a problem-solving product, and evaluating the product gives more insights into the problem. Which results in a build-and-evaluate iterative design loop. This can be seen in the proposed framework in Figure 2, where the IS research is in the middle including the developing and evaluating activities. The design is based on both the environment (left) representing the practical needs of the appropriate environment and on the knowledge base (right) representing the applicable knowledge. This makes the design both relevant (useful) and rigorous (true). The environment can be improved when the artefact is applied as an application, while the knowledge base can receive new additions from the design evaluation and research.

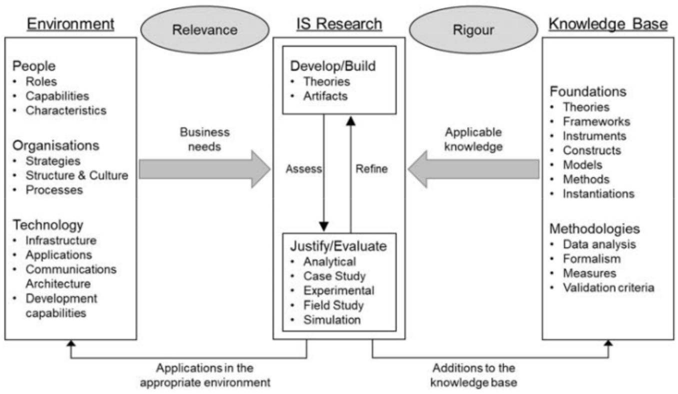


Figure 2. Information systems research framework [28]

2.3. Research design (Case study)

According to the design science research method, the goodness and efficacy of the artefact can be demonstrated through a well-selected evaluation method [28]. They propose 5 categories and 12 specific methods, one of which is a case study as seen in Table 3. In this thesis, a case study will be used.

Observational	Case study: An in-depth study in an appropriate environment
	Field study: Monitor use in multiple projects.
Analytical	Static analysis: Examine the structure of artefact for static qualities.
	Architecture analysis: Study fit of artefact in technical architecture.
	Optimization: Demonstrate inherits optimal properties of the artefact.
	Dynamic analysis: Study artefact in use for dynamic qualities.
Experimental	Controlled experiment: Study artefact in controlled environment.
	Simulation: Study artefact with artificial data.
Testing	Functional testing: Black box testing. Look for failures.
	Structural testing: White box testing. Test holistically by some metric.
Descriptive	Informed argument: Use knowledge base to build a convincing argument.
	Scenarios: Construct detailed scenarios around the argument and demonstrate its usefulness.

Table 3: Design evaluation and demonstration methods [28]

The primary goal of a case study is to give a comprehensive view and propose a solution to a large-scale problem by analysing single or small units [29][30]. There are two valuable uses for case studies according to Siggelkow [31]: demonstrating through real-life situations the occurrence of a phenomenon, and serving as a base for new research by showing existing gaps and analysing the proposed solutions. However, case studies have the limitation of representing a single or small case, and therefore making generalizations. Nevertheless, this type of research can be used as a base for developing a hypothesis, which can be further tested [32]. In this thesis, the case study will serve the use of evaluating the proposed framework. First, requirements will be set for the results of the framework's application and what the framework itself should be. Then the framework will be applied to a real-life HMI redesign, after which it will be assessed how well the requirements are met.

3. Theoretical framework

This chapter provides the theoretical framework. It consists of five parts. The first part describes the aspects of current challenges in manufacturing. The second part is an overview of the different existing Industry 4.0 technologies and the applications in HMIs. The third part examines methods for HMI development in academia, followed by frameworks and guidelines for developing and implementing Industry 4.0 technologies integrating the human factor. And lastly based on the theory a requirement list is created for the future framework.

3.1 Current challenges

As discussed previously, the integration of Industry 4.0 solutions is connected to all organizational levels (Figure 1.) and aspects, therefore various challenges can be observed in practice-focused research. The HTO factors as deeply interconnected, therefore it is hard to observe their influences separate from each other, which is why they will be presented in one section.

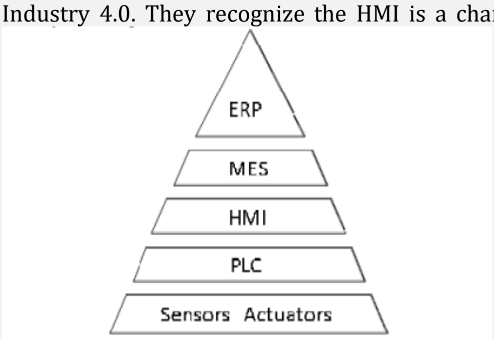
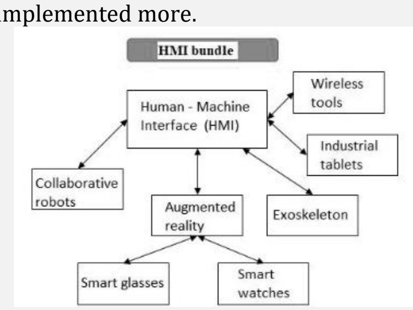
A study on technological incidents that have occurred in 2014 in France concluded that 63% of the incidents were caused by human errors and 37% by material failure [10]. Human errors are in Level 2 of the manufacturing control system, as the operator supervises and controls the machines [4]. While material failures can be connected to multiple levels- the quality and type of products used in Level 4, having the right material identification, sensors, and control system in Level 1, and the actual storage, handling, and machine manufacturing process in Level 0. The study had concluded that it is essential to understand the organizational context, which has resulted in the causes. They had also observed that several of the largest shortcomings were the production process itself, the training and organization of personnel, and the work tasks. Pacaux-Lemoine et al. [10] also point out that operators are expected to handle any situation efficiently. In any unpredictable, dangerous, or failed event humans need to be coordinated, efficient, and rapid thinking which is what Trentesaux and Millot [32] call "magic humans". Creating for the 'magic human' could lead to machines and HMIs unsuitable for their end user, which could make them complex, hard to operate, and dangerous for the actual operators. This is emphasized by Fast-Berglund et al. [33] as for information and communication technology tools, part of which are HMIs, it is essential that the designer does not expect or assume the operator's use of information, but rather base it on real-life observations. This can be observed in a case study with a Danish manufacturing company transitioning to Industry 4.0 where the engineers have had limited knowledge of the work system operations (Levels 0-2) and had developed technical solutions without involving operation level works, resulting in non-practical and non-valuable solutions [7]. Furthermore, their decision-makers had failed to identify a need and justification for the developed solutions, resulting in even less valuable designs.

In a different case study done by Lodgaard and Dransfeld [34] on a Norwegian equipment manufacturer it was observed that the organization was focused only on short-term problems and solutions, which according to the writers is preventing them from reaching the digital transformation they are striving for. They were creating solutions without understanding the holistic nature of the problems, resulting in design not based on their actual problem, but rather on fixing the observed effects. Therefore, developing and implementing tools that aid the improvement of the organizational structure will help the company to balance long and short-term issues and remain competitive in the market. They emphasize the need for implementation of technology in stages and more importantly that the technological solutions are aligned with the companies' business strategy and level of digital maturity. The company also needs to facilitate collaboration between different teams to successfully develop an I4.0 compliant HMI.

One example of how understanding the current state can aid the transition to Industry 4.0 is through the factor of digital maturity. Digital maturity is one of the organizational aspects that play an important role in the type and level of integration a technological Industry 4.0 solution can have [34]. One of the pillars of Industry 4.0 is real-time data collection and analysis [35]. For transforming manufacturing processes into Industry4.0, it means that all data should be digitalized. This is valid for all levels in Figure 1. One common challenge observed in Level 2 and Level 3 in manufacturing facilities is that manual and paper-based documentation is utilized to support everyday tasks [35]. This is not only time-consuming but also means that critical data can be lost and is stored on paper sheets and cards.

3.2 Industry 4.0 technologies in HMIs

Due to the various and demanding environments of Industry 4.0, a new HMI model is needed to cater to the new needs, more specifically a tailored solution to specific scenarios and stakeholders [24]. In the paper by Papcun et al. [9] they distinguish between 4 revolutions of HMIs. HMI2 is what would still be considered the standard HMI found in most manufacturing machines- a visualization of the current state of the machine with a touch-screen control panel for the operators. HMI3 is a platform that can adjust according to the authentication (operators or remote managers) and HMI4 implements augmented and virtual reality technology to aid the operators. To reach HMI4 all the previous ones are required. This is further discussed by Zheng et al. [35] who propose an HMI cloud-based smart control system that has multiple users and purposes- operators for controlling the machines, production supervisors for task scheduling and management, and management for data analysis and production prediction. One of the established factors for how HMI developments could take shape within I4.0 is technology. Therefore, a literature review has been made on the existing technological applications, using Table 1 as a base. This has been done by searching the terms – "specific Industry 4.0 technology" AND "HMI" AND "Industry 4.0". The results are written in Table 3. What can be seen from this literature review is that the functionalities and value of the HMIs are greatly dependent on the existing technological and organizational structures.

Technology	Literature research
Simulation	According to Assawaarayakul et al. [36], the HMI is part of the Automatic pyramid, as seen in Figure 3. Their paper investigates the integration of digital twins into an existing production system for Industry 4.0. They recognize the HMI is a channel for interaction between people and systems.  **Figure 3.** Automatic pyramid [36] In a paper by Guerra-Zubiaga et al. [37] on developing a digital twin for I4.0 system with manufacturing automation case studies, the HMIs are used as part of the digital twin where a virtual HMI connected to the PLC is created. They propose that in the event of no physical HMIs, the virtual ones can control both (physical and virtual) manufacturing systems.
Big Data and Analytics	Mendes et al. [38] categorize all technologies used in Industry 4.0 as either HMI or connectivity related. The HMI bundle includes embedded devices to assist operators in manufacturing activities, through various technologies as seen in Figure 4. They suggest that depending on the production logic of the company the adoption of these two technology bundles will differ. If flexibility is dominant then, HMI bundle implementations happen to a higher degree. And if the company has fewer product variations, and focus on quality and efficiency then the connectivity bundle gets implemented more.  **Figure 4.** Overview of HMI technologies [38] Bellavista et al. [39] propose in their paper on design guidelines for big data gathering in Industry 4.0, a multi-layer architecture for data gathering, streaming and analysing. The bottom layer, the "Mirroring layer" consists of an operation technology layer and a machine layer- this is the manufacturing site. The Operation technology layer consists of multiple components as seen in Figure 5. The HMI-forwarder has 3 duties to retrieve data from machines and validate and serialize the data before ending it to a "Kafka Broker". The HMIs here are seen as a channel for obtaining data from the physical world.

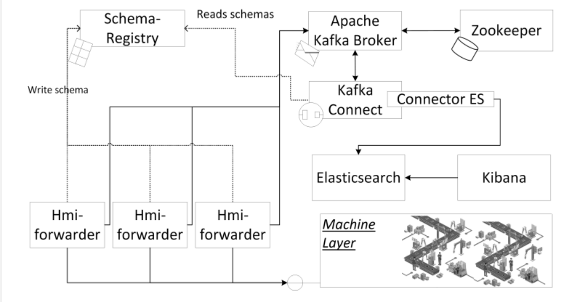
	 **Figure 5.** Operation Technology Layer Scheme [39]
Cloud Computing	In a paper by Siddique et al. [40] they successfully create a prototype for virtual controlling and monitoring of industrial parameters using cloud computing through HMIs. Their aim is to compare the virtual control of the HMI (though computer or phone) vs the physical control. In the prototype, they have a real-time representation of all parameters and a visualized live production process. The findings of the paper show that 52% of the operators prefer using a website, while 29% want to be on-site to control the machines. Perez et al. [41] propose remote rendering in industrial HMI applications as opposed to HMIs with a high-end graphics card, 3D acceleration support, and enough memory to render. Cloud computing is used to facilitate the streaming to the HMI applications as well as sent back the users' interactions with the model and send them back to the server.
Cyber-Physical System	A paper by Garcia et al. [42] investigates how can a person using the natural human-machine interface (NHMI) control, coordinate and cooperate with an industrial cobot in a cyber-physical system. NHMI is a machine interface, which can be operated through non-tangible key interfaces- like voice recognition, gesture recognition, and enhanced reality. The paper proposes that the NHMI will be better suited for the complex interactions required between the human and the robot.
Cybersecurity	There were no relevant papers on the influence of Cybersecurity on HMI design in machine manufacturing and Industry 4.0 context.
Collaborative Robotics	In a paper on the implementation of intuitive collaboration between man and machines by Gualtieri et al. [43], the need for an NHMI is expressed again, as it allows for natural and bidirectional information flow between the robot and the human. This paper adds to the Industry 4.0 NHMI a fourth key interface- the prediction of the operator's intentions. It allows for improved collaboration and safety, as they depend on the understanding between humans and robots.
Augmented Reality	According to Stark et al. [44], the increasing number of connected devices through the Internet of things in a digital factory can no longer be monitored and controlled through a normal HMI. Therefore, they propose an interaction through a graphical interface in augmented reality, which would be the new modern form of HMIs. Zhu et al. [45] look into a visualization of digital twin data by using augmented reality. They also claim that the HMI is not the ideal method for visualization, proposing head-mounted displays (HMD), hand-held displays, monitors, projects, and 2d smart glasses. According to them, the HMD can provide the most intuitive and flexible and hand-free interaction, from any position and angle inside the manufacturing environment.
Additive Manufacturing	Both GF & RV [46] and Eiriksson et al. [47] propose in their papers that additive manufacturing requires a more flexible and intuitive interface, by making use of mobile devices, with a touch screen like tablets and smartphones.
Systems Integration	In a paper by Papcun et al. [9] on the HMI in the concept of Industry 4.0, they discuss the development of platforms, where the layout of the visualization can be adjusted accordingly to the authentication- operator, or managers and their device type. The HMIs cater to all stakeholders in the organization, including the managerial levels.

Table 4. HMI-related influences and applications for Industry 4.0 technology

3.3 HMI development

In academia, the literature available for HMI development is mainly focused on the automotive industry, where the HMI serves as the panel through which the driver and the vehicle are connected. The nature of this type of communication is vastly different from that of an industrial setting, which is why only papers related to the manufacturing applications will be considered. In most literature and manufacturing organizations the current focus is primarily on technical deployment, while user-centricity is up now neglected [12][34][48]. This can be further seen in papers developing HMIs for Industry 4.0 only within the technology context [24][49]. According to Ardanza et al. [49], the HMI's recognized functionalities are:

- Monitoring and visualization of real-time process data
- Supervision, allowing the adjustment of the working process directly from the HMI
- Alarms management to recognize malfunctions or misbehaviour
- Controlling and keeping the process variables within safety limits;
- Storing and reviewing recent activity, providing accessing methods to retrieve the recent data and metadata of the manufacturing process

From observing them, it can be deduced that they are based on the interaction between humans, technology, processes, and the organization. However, the two main requirements taken for the

HMI in the paper are robustness (the hardware) and operations (the software), which only reflect the technological aspects. Another paper by Leal et al. [24] uses a model-driven design to conceptualize HMIs in Industry 4.0 era but also focuses only on the technological deployment. A model is a simplified reproduction of a planned or existing system with its processes and attributes. Such a model includes the behaviour, structure, properties, constraints, and requirements of the system [50]. The use of a model-based development can have great implications in HMIs, as they are systems compiled of multiple qualitative models including functional, behavioural, and structural information. Models of complex multi-dimensional systems describe their interrelations-interactions, effects, and influences between the models, the outside environment, and the users. Model-driven engineering uses models as a central part of developing systems. This approach is utilized to model information about the system's requirement, design, analysis verification, and validation activities and it can serve as a reliable and consistent source of information and traceability for decision-makers.

3.4 Existing frameworks and guidelines

There are five frameworks and practical guidelines for developing new user-centred solutions within the Industry 4.0 context which will be discussed. Kadir and Broberg [7] propose a framework for a systematic and comprehensive approach to implementing and developing new digital solutions to gain a holistic understanding of the organizational work system, before starting the implementation phase. It is based on ten industrial cases and combines elements from human-factor/ergonomics (HF/E), system modelling, and strategy design. Their framework begins with defining the vision, value, and scope of the new design, followed by understanding the current state of the work system. They have defined five main categories which constitute the current state- finance, organization, work practices, space, and technology. Those states have their challenges, objectives, requirements, and targets. For their case study, the authors applied a seven-step approach to testing the framework, which can be seen in Figure 6. The framework shows the type of information needed to develop a new solution, however, they do not propose a systematic way of acquiring the information.

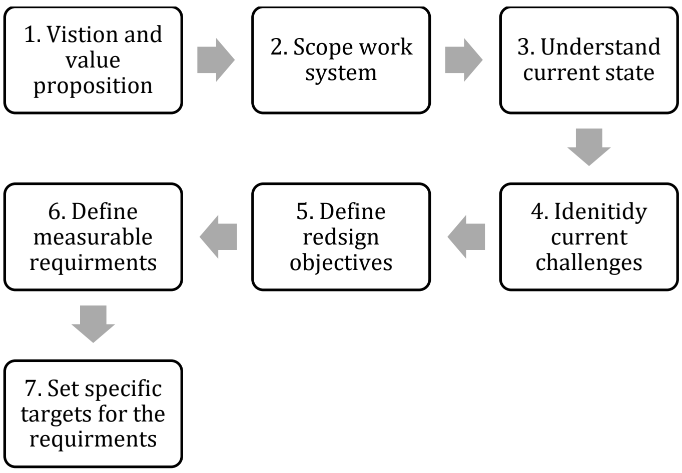


Figure 6. Seven-step approach to testing framework [7]

Another framework created by Gräßler et al. [51] aims to integrate the human factor in an already existing or planned cyber-physical production system. They propose a five-step framework, as seen in Figure 7, and have used a model-based development to integrate the different the human-factor. This framework begins by clarifying the situation consisting of: "the general system requirements (e. g., technical, economical, time, safety), product features to be manufactured, control systems and information on the existing machines and manufacturing technologies". The following steps investigate the type of interaction between the roles in the different use cases, resulting in an extension of the initial requirements. The framework, however also does not provide any practical guidelines and methods for obtaining the information at any step.

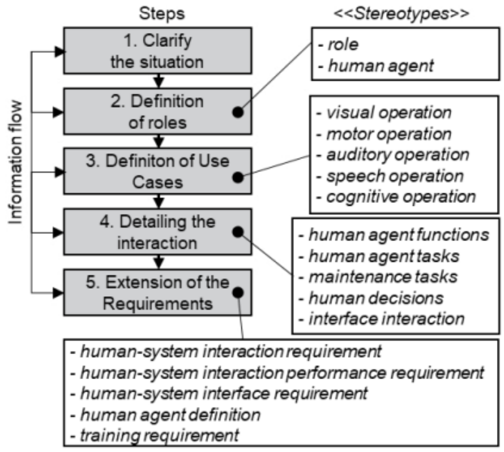


Figure 7. Framework for integrating human factors in cyber-physical production systems [51]

Neumann et al. [20] propose a framework for considering human factors in the conceptualization, design, and implementation of new technologies within the Industry 4.0 context. The framework has five steps, which can be seen in Figure 8. The framework has similarities to that of Gräßler et al. [51], however, it is not bound to one type of technology, but rather can be used for any. The authors conclude that to apply the frameworks in practice, practitioners will need supplementary tools and support.

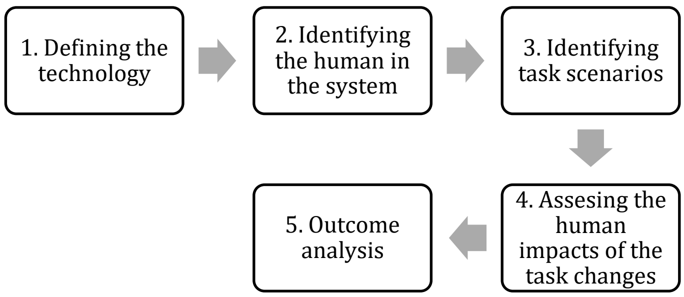


Figure 8. Framework for considering human factors for new technologies within the Industry 4.0 [20]

According to Lodgaard and Dransfeld [34] for successful integration of an HMI in-depth understanding of the organizational structure and culture is required. In their case study, a less systematic but similar approach to that of Kadir and Broberg [7] was taken where the authors used structured and unstructured interviews, field visits, observations, documents and database reviews, to get a comprehensive view of the company's organizational structure, digital maturity, and HMI use. This is the only proposed research method or tool for obtaining information for designing a human-centred HMI in Industry 4.0 era.

Lastly, the principles and guidelines for HF/E design and management of work systems by ILO and IEA [52] will be looked at. This document provides six practice-oriented guidelines based on the principles developed by the two institutions- The International Labour Organization and the International

Ergonomics Association with aims to help practitioners, companies, and researchers to manage, and integrate the human factor and ergonomics in their work systems and developments. The six guidelines are as follows:

- Guideline 1- Use a systems approach.
- Guideline 2- Consider all relevant characteristics of workers
  - 2a. Consider demographic characteristics, physical and cognitive capabilities and limitations.
  - 2b. Provide workers with appropriate tools, training, and control to perform work.
  - 2c. Design work systems to be safe and to engage people in ways that maximize worker and work system safety and sustainability.
- Guideline 3- Apply participatory HF/E methodologies.
- Guideline 4- Incorporate proactive measures to ensure worker safety, health, wellbeing, and sustainability.
- Guideline 5- Tailor HF/E design and management of work systems to characteristics of the organization.
- Guideline 6- Sustain a continuous learning process for evaluation, training, refinement, and redesign.

It can be observed that many of these guidelines are already mentioned in the prerequisites found for developing a successful HMI, or Industry 4.0 solution. The application of these guidelines will be further discussed in the Framework Requirements section.

3.5 Framework Requirements

The goal of this chapter is to identify the important factors needed for a successful HMI solution in Industry 4.0 era. As the aim of the framework is to be used at the beginning of the development process, its application should yield a base including all of these recognized factors. Therefore, the success of the proposed framework can be assessed by how well its use results in the required aspects. The requirements for the framework are based on the academic literature presented in this chapter.

Human aspect

The nature of the human-machine interface implies interconnectivity between the human and the machine and its process. The need for humans in Industry 4.0 is not going to decline and the future of HMIs is expanding the number of users, scenarios, and purposes they will cater to, creating an even deeper need to understand and incorporate the human factor in the design process [35]. According to Åkerman et al. [53], information system tools (ITC) should provide the operators with the information they need and not what design experts presume they need. This is further shown through the concept of the "Magic human" stressing the need to understand and appropriately design for real people and their physical and cognitive ergonomics. In a case study by Åkerman et al., [53] on the implementation of ITC systems in Industry 4.0 context, they had found that the function of the new system, which was most extensively researched and with a clear problem and goal for change, had tested as the most effective one. They further point out that the tool had been designed without any meetings or discussions with the operators, which had been raised as an issue by the operators during the testing. The second guideline by ILO and IEA [52] talks about considering all relevant user characteristics, which can also be seen in various degrees of detail in the works of Neumann et al. [20] and Gräßler et al. [51].

Organizational Structure and values

Both the HMI and Industry 4.0 cannot exist outside the context of an organization, however often in academia this differentiating factor is not considered, as the environment of an organization is assumed to follow the generally accepted best practices and similarly to the phenomenon of the 'magic humans' organizations are considered to work perfectly. However, as they are created, driven and operated by people, the same type and amount of variety and limitations can be expected to be found in an organization. Organizations have various attributes which can drastically distinguish them one from another like structure type, information flow, culture, knowledge and team structure [34]. Just as importantly they have values, visions and strategies, which all influence and impose limitations and objectives on the outcome of a development project [7][10][54]. Knowing what needs to be changed in the organization though the integration of a new system is key for its success [33][34]. As technology is seen as an enabler for business strategies, Industry 4.0 solutions need to connect to all organizational levels and HMIs and HF/E design should be a tailored solution for specific scenarios and stakeholders and work systems, understanding and incorporating the organizational characteristics is needed for an effective and useful design [2][3][24][34].

Operational and manufacturing processes

By definition industrial HMIs are bound to manufacturing processes, as they are the intermediate medium between the machine and the human, allowing for manipulation, control, and overview of the processes. As discussed the influence and scale of the systems and scenarios to which HMIs will cater within Industry 4.0 are growing and starting to include not only the manufacturing but also operation processes like task scheduling, management for data analysis, and production prediction. Another objective for understanding the current work processes is due to the underlying need for I4.0 to capture and analyse data, which could be achieved through work tasks digitalization. However, just like in the previous two sections about people and organizations, the workflow process can be flawed, and differ in reality versus on paper. This is also observed in the study by Pacaux-Lemoine et al. [10], where two of the main reasons for production failure are the manufacturing processes and the work tasks. This is why understanding and basing a design on the real work processes is a component found in all of the discussed frameworks. In addition, in the case of an HMI redesign its objective can be a solution to a recognized problem within the work processes. Lastly, one of the HF/E design guidelines is focused on proactively considering and ensuring the workers' safety and wellbeing, which is heavily dependent on the nature of their work.

Technologies

Both HMIs and Industry 4.0 are developed based on technology and therefore cannot be discussed without its context. And for both the design possibilities are dependent on the digital maturity of an organization [34]. By looking at Table 3 it becomes evident that for most Industry 4.0-related HMI applications, specific technology enablers are needed. Furthermore, technology is also part of each of the frameworks looked at and is the base for most existing development frameworks for I4.0 solutions or HMIs. However, within the context of HMIs, it is interconnected with people, and therefore technologies should be considered as systems with their influences on the environment, the organizations, and the people.

Practical Guidelines

Lastly, the framework should integrate practical methods for acquiring and structuring the needed information. As seen in the Introduction chapter, relevant literature points out a gap in research for practice-oriented guidelines, further seen in the examined frameworks, as they are not supplemented with application methods. By incorporating them, a systematic approach can be ensured, as the practitioners can follow established methodologies. This need is also reflected in the first and third HF/E guidelines, which call for systematic documentation and the use of HF/E-focused methodologies.

4. Framework

Based on requirements formed in the theoretical background chapter and the established gap analysis a new framework is proposed for the beginning and the research phase of developing and (re)designing an HMI within the Industry 4.0 context. The framework is built upon the existing work of Kadir and Broberg [7], Gräßler et al. [51], Neumann et al. [20], and Lodgaard and Dransfeld [34] with the addition of guidelines and tools for practical application. From the theoretical research, it becomes clear that the development of an HMI within the Industry 4.0 era, requires an understanding of the human aspect, the organization structure, and its values, the operational and manufacturing processes, and the available technologies and technological knowledge, as a solution cannot be created outside of that context. Starting a development project without having a current state analysis of the developing organization and the stakeholder's needs, could lead to designing solutions, which cannot be executed and require modifications, do not fit the market's needs, or are not in line with the organization's strategy and vision. A common design challenge is the relationship between freedom of action, modification cost, and product knowledge, as seen in figure 9. This is because often new factors about the design objective are discovered while the development has already started, making design changes costly [55]. The proposed framework suggests that design development should only start once the current state and work system scope are fully defined and known. This way all of the needs and limitations for the solution will be available to the design team, allowing them to make educated choices, thus minimizing the possibility of needed modifications, not meeting the market's needs, and fitting to the organizational vision. The framework aims to recognize and systematically record the users' needs and the system's limitations, on which the solution can be based. The selected methods are HF/E focused and try to provide a systematically documented foundation that allows for design decisions to be traced back in needed for future projects and redesigns. In addition, previously discussed frameworks follow a sequential order, which although theoretically sound often does not reflect in real situations. The idea of creating a solution purely based on the values and vision of a company even though good, creates a restriction on the source of innovation drivers in an organization. Often in reality the entities responsible for recognizing a gap, or generating an idea for improvements are the engineers, sales representatives, or even employees from the production floor, who might not be aware of or trying to follow the values and vision of the company. Innovation drivers should not be limited by the organization, but aid the strategy and mission it is trying to achieve. Otherwise, they could become disruptive [8].

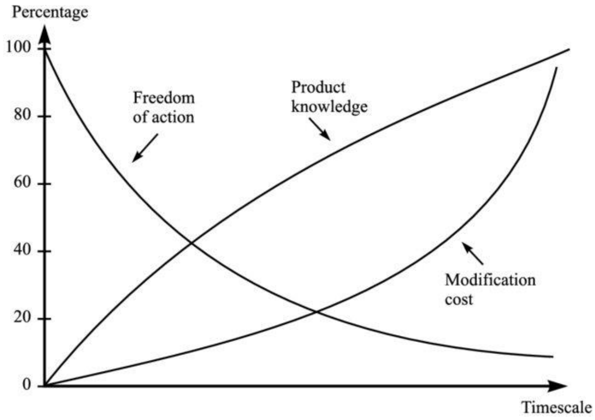


Figure 9. The relation between "Freedom of action", "Product knowledge" and "Modification cost" is shown [55]

The framework (Figure 10) can be described as follows. The process should begin with a design objective (the work system scope), as it will set boundaries on the type of solution that will be created. The work system scope can be a general objective like "creating a more user-friendly machine" or more specific like "creating a more user-friendly machine-use experience only though the current possibilities of the HMI". In both of these scenarios to fully understand and define the scope, a current state analysis should be carried out to get a full view of all the factors influencing, enabling, and limiting the design of the system. As the current state analysis is completed, the work system scope will become fully defined together with the needs and limitations of the new solution. Separately the values, vision, and future strategies of the organization need to be clear to the development team, as they will guide how the solution should be embodied to best fit the organization. These three elements will serve as the base of the requirements and solution of the (re)design. It is important to note that the work system scope can be set at the beginning of the project as an objective, however, its full boundaries will become visible throughout the current state analysis. Thus it is possible for the work system scope to be redefined, as the project progresses. This is one of the major differences from the work proposed by Kadir and Broberg [7], as, unlike their work, this framework encourages a reassessment of the work system scope as more information becomes available, a new approach, resources, and knowledge might be needed to best serve the aim project. As set at the beginning of the thesis the framework's scope is limited to identifying and matching the organization's needs, wishes, limitations, vision, and values and does not focus on their transformation into requirements.

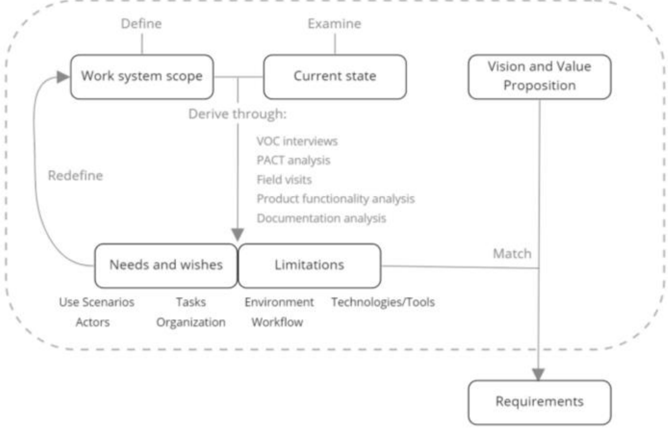


Figure 10. Proposed framework

4.1 Defining the work system scope

Defining the work system scope sets the focus of the (re)design. Most commonly the work system scope will be defined during the preposition of the (re)design as its objective. Industry 4.0 and the HMI can span and involve the integration of many technologies, as discussed in the background research. However, in most organizations, the development of these solutions will be carried out by different teams and possibly departments. This is why defining the scope of the work system might even be selecting a solution that will be developed within the possibilities and limitations of a set group of people/team.

As the current state's research progresses new interconnections and dependencies can be discovered, which could change the scope of the work system, either by excluding or including said connections. The work system scope should be commonly understood by all people involved in the project, best in a written format. Taking as example the previously mentioned objectives of "creating a more user-friendly machine" or more specific "creating a more user-friendly machine experience only though the current possibilities of the HMI". The current state will give a picture of all scenarios, actors, tasks, and technologies throughout the lifecycle of the solution, from where it can become clear which design and technology decisions can be executed by whom, which could thereby change the scope. For example, for creating a more user-friendly machine, it might be assumed that as the HMI is the main interface for communication, the focus of the redesign will be on it, but through the current state analysis, it has been discovered that most of the issues experienced by operators happen during the maintenance and hazardous cleaning of the machines. This would therefore require a re-evaluation of the work system scope and either redefine it as "creating a more user-friendly machine experience only though the current possibilities of the HMI" or expand the boundaries by involving the machine development team. Another application for redefining the scope is the need for knowledge recognized by the initial team, as HMIs machine manufacturing is a multi-disciplinary task, it might be discovered that a certain technology or case-specific knowledge is missing and depending on the project this might be a limitation or reason for changing the premise of the scope.

4.2 Current state analysis

The current state encompasses everything that influences the HMI (the solution), therefore the current state should be looked at as the whole lifecycle of the system. It will not only focus on the use scenarios once the HMI is in use at a client but also on the development stages, maintenance, and end of life. This is of value, as every organization has its workflow and development limitations and needs, which need to be considered before designing the solution. The analogy could be made that the current state is like mapping a customer journey, where the work system scope (the objective) is the part of that journey that the solution is aiming to help. Therefore, it is important to fully understand what is currently happening and to observe where and how improvements could be done. There are many ways to acquire and structure this type of information, however here are proposed methods that have been used during the case study and throughout academic literature. The approaches aim to create two types of deliverables- a lifecycle map and a product functionality map.

Lifecycle map

According to Lodgaard and Dransfeld [34] and Nardo et al. [4], the development of an HMI in the Industry 4.0 era requires consideration and understanding of all the organization and its levels. Therefore, the lifecycle map should integrate all the stages and organizational aspects of the selected system (product/solution).

The first step is to identify all the stages. This will serve as a base from which the different influences and influencers, scenarios, and limitations can be derived. After that through the suggested methodologies all the properties can be added to each stage- its actors, their tasks, their technological and organizational limitations, and influence on the system. Once all of this is mapped and structured, the information can be used to identify which influences and their properties affect the objective of the solution. For example, if the objective is to create a safer machine, then all of the aspects that influence the user's safety should be considered and looked at. However, this cannot be done without having a complete overview of the whole lifecycle, for example, it can be presumed that the use of the machine is optimized for user safety, however during the lifecycle analysis it can be discovered that during the demolition of the machine dangerous chemicals can come in contact with the users. Once again showing the constant need to re-evaluate the work system scope. Another aspect is the executing team and their current workflow, just like the other processes added to the lifecycle map, it is important that they are aware of their design and process limitations and needs.

The main subject of this analysis is the workings of organizations, which are complex structures therefore comprehending and mapping them, requires different approaches. Most companies do not have a document with their mapped organizational structure, thus obtaining that knowledge needs to happen through observing and communicating with the people within the organization- the employees. The first and most fruitful method is verbal structured interviews. Voice of the Customer (VOC) is chosen, as it provides a methodology for conducting, structuring, and analysing interviews. The Voice of the Customer is used to obtain and transform qualitative customer expectations, preferences, and aversions into quantitative system requirements which can be used within engineering fields. The goal of the VOC is to incorporate the customer in the design decisions at the earliest stage and to do so in a systematic and easy to trace back way [56]. Although in its original stated purpose the VOC is focused on customers, it could be argued that all stakeholders in the solution's lifecycle are its "customers". As they have their influences, needs, expectations, preferences, and aversions to the system. Furthermore, all employees (who are also stakeholders) can be viewed as "users" of their organization. Thus leading to the conclusion that the VOC can be used not only for customers and product analysis but also for stakeholders and system lifecycles and employees and organizations. This makes the methodology highly applicable in the needed analysis, as the lifecycle of an HMI begins in its development in one organization, its multi-levelled use in potentially different organizations, and followed by its maintenance done potentially as a collaboration between these different entities. Depending on its application there are many ways for conducting the VOC. For this paper, a detailed explanation of how the interviews should be carried out can be found in Appendix A.

The process of creating the lifecycle map is iterative, as with every new set of information, the previously acquired knowledge should be validated and if needed adjusted. As it is likely that no single person in the organization will know with certainty the lifecycle, all its stages and properties, the selection of people who are interviewed should be based on the already identified actors. For example, the interviewer is part of the development team of an HMI and they have created a lifecycle map including the development of the machine itself. As part of that stage, they are aware of the type of people involved. Therefore, they will interview the corresponding people in detail about their work tasks, activities, responsibilities, and influences on the objective. It is possible that the development team is aware of the whole lifecycle and is capable of mapping all of the internal stages and their properties, however, they should validate their work with if not each most of the actors. For the stages which are vague and not a lot is known about, interviews should be carried out with the identified actors. One suggested method for documenting the lifecycle map is creating a table with the stages and all the properties. This way the information is visually available and easy to share and communicate within the team. To structure and map the VOC interviews, the extracted verbatims should be classified according to the corresponding lifecycle stage. An example of these methods for structuring information can be found in the case study.

Interviews have a limitation on human expression and information can likely be missed. Therefore, field visits and observations can provide additional insights into how the tasks and activities of the stakeholders are being carried out. This type of analysis should be targeted to stages and scenarios of which the research team is not part and therefore they can learn more. Furthermore, field visits to clients, where the HMIs are being used and observing how they are being handled in reality versus their intended use, can be highly beneficial. Viewing how an individual is carrying out their work naturally, can provide insights on what the tasks they are doing exactly are while understanding why this is the preferred method can be verbally communicated. Therefore, both forms of research are suggested. Lastly, any existing documentation of relevance should be considered and analysed. This would depend on the scope and level needed for the objective of the project. The documents can for example be mapped processes, project reports, customer communication reports, manuals, customer requirement specifications, information flows, project rationales, ERP systems, data analyses, etc. However, a limitation of this method is that if the information is not well documented it could be inconsistent or missing. A second potential limitation is discrepancies between the written documents and the reality, therefore making some of the information untrustworthy. These deviations cannot be observed unless they are validated with employees, which should be done through VOC.

The next approach used to structure and analyse all of the properties within the different lifecycle stages is a PACA analysis. PACA- People, Activities, Context, and Technologies/Artefacts is a method used in interaction design to analyse the user experience of a user interface [57]. However, the approach can be used to analyse any product, system, or situation, while given the context of whom, what, where, and how the users interact with. It can provide an overview of the types of users and their profiles, the activities they carry out, the context and environment of their use, and the artefacts and technologies they have available. The information needed for the PACA analysis should be obtained through the VOC, field visits and observations, product functionality analysis, and documentation research.

The PACA analysis gives insight into the already available and used technologies within the system. However, a wider Industry 4.0-related analysis is needed of the current technological state for the design team to know what is possible. Industry 4.0 technological scans are available in literature, however, they require a lot of resources and their level of detail is too big. Therefore, an adequate solution might be to use Table 1 and Table 4 and create a quick assessment of the organization's technological state and its implication within the companies' strategies, the project's objective, and the HMIs.

Product functionality map

The product functionality map of the HMI is needed in case of a redesign. This way a comprehensive view of the existing possibilities and limitations can be created. There are various ways of doing a functionality analysis and the method should be adjusted to the level of detail and focus desired by the design team. The proposed method is only focusing on the functions and actions and not on the technical structure of the system. The objective of this map is to visualize the possible interactions a user can have. This can be used then as a direct comparison to how the system is used in reality and what are areas of improvement, but also as a base for what is already possible with the software. The proposed method has been used in the case study, with the objective of better usability. Therefore, it has been tailored to map the product's functionalities in a way that can later be analysed according to the project's objective. Some functionality analyses are based on derived functions and how they can be executed within the software, however, this approach is based on the interface's screens and the actions they offer the user. The main reasons for choosing this method are the objective of the analysis- usability and the simplicity of the HMI, as executing one function can be done only in one way. More complex software could require a different approach.

The mapping is done in a table with 6 main columns, an example can be seen in table 5, where only the message function is described. The first one is the screen or tab, followed by all the possible buttons or interactions. The number of columns needed will depend on the number of levels, as each level should have its own column with possible interactions. This type of tree mapping can be useful both for the HMI developers, as they have a documented representation of where each function is, but also for usability analysis like investigating the most commonly used actions and how many steps for execution they require. The next column is a description of the activity, where its properties, colours, and general description can be added, followed by a notes tab for writing observations and questions during the analysis. Lastly, the purpose of the screen/tab is described. This would encompass the reasoning behind the design choices. As the analysis is done any notes, observations, and questions regarding a function should be noted in a separate column as well. It is recommended that the analysis is validated. An organization may have this information already available in which case this analysis can be skipped.

Function	Sub-function	Actions	Description	Observations and Notes	Purpose and Additional information
Messages	Current messages		Shows alarms in type of severity (red and yellow), module number, alarm number and description	The messages cannot be filtered.	The messages show current and passed alarms, which are triggered by different sensors set by the PLCs. They are colour coded in red and yellow. Red meaning the machine has stopped and yellow is warning- the machine runs but needs attention.
	Message history		Shows alarms in type of severity (red and yellow), module number, alarm number, description and a time and date stamp of its occurrence.		

Table 5. Example table of product functionality mapping with 6 columns from the case study

Remarks

The proposed methods aim to serve as a guide on the type of information needed and suggest tools for obtaining and structuring it. However, if an organization is to apply the framework, they might discover that a lot of the needed information is already available to them. In this case, an evaluation should be done on what is known, what needs restructuring, or still missing. Nevertheless, the methods' objective is to identify and support the acquisition of the needed types of information. Therefore, it can be used regardless of the amount of pre-existing knowledge.

4.3 Analysing the information

Once the lifecycle and product functionality map are created the design team can focus on the objective. This would require identifying all of the areas with the lifecycle that influence or are being influenced by the objective and re-evaluating the work system scope- the boundaries through which the solution can be created. Depending on the project further analysis of the data could be performed to derive further information about the objective. For example, in the conducted case study, as usability was the main objective the product functionality map was evaluated using Jakob Nielsen's 10 usability heuristics. The lifecycle map, served as a base to conduct PACA analysis and field observations, as well as to categorize all of the VOC interview statements. Using the VOC methodology, the verbatims were grouped and commonalities were derived. Based on all of the information the needs of the users and limitations of the organization were described.

4.4 Requirements

The vision and the values of an organization should be embedded in all of its activities, therefor a development project's aim is to support that vision. Once the needs and limitations of the project are recognized the requirements should be created. They should be aligned with the companies' strategy. This framework will not propose methods for creating requirements, as its primary focus is on obtaining, structuring and analysing information during the beginning stages of a project. If the organization following the framework with the suggested tools has chosen to utilize the VOC methodology, it contains steps for transforming the obtaining knowledge into requirements.

5. Case study

This case study aims to demonstrate the real-life scenario application of the proposed theoretical framework. As mentioned previously the framework and the suggested methodologies should be tailored to the specific project they are applied in. The goal of this chapter is to show what adaptations were made and to serve as an example of the framework's implementation. The selected Dutch manufacturing company wished to redesign its HMI with the goal of integrating Industry 4.0 technologies and improving machine usability. Therefore, they are a suitable match to investigate the usability of the framework. First background information will be given about the company, after which the application of the framework will be discussed, followed by the findings. The case study has been conducted over the period of 6 months by the author in collaboration with the project lead of the software department.

5.1 Company background

Background research about the case study company has been conducted through interviews, field visits, document analysis, and observations. At the start of this project, the company had recognized usability issues with their current machine designs, part of which are the HMIs. As previously mentioned HMIs are bound to the production processes of the machines, and the design of the machines is influenced by the type of activities, organizational structure, industry, and clients. Therefore, to properly understand the context of these issues employees were interviewed about their current development processes. An interesting observation was made during this investigation- employees were raising issues relating to the lack of design activities and missing design considerations. These issues directly correspond to the finding in the theoretical chapter. This is the second value of a case study- demonstrating through the real-life situation the occurrence of a phenomenon. This section will first provide the background information on the company to give context, followed by the mentioned production process issues.

Types of machines

The machine building company is family owned and based in the Netherlands. They began manufacturing machines for the tobacco industry, and currently are in the detergents and paper industry. They have positioned themselves as machine builders offering custom machines, with short lead time, modularity and flexibility.

The company builds packaging and assembly machines and they offer custom or catalogue designs, the former requiring a research and development phase. The machines are automated and are controlled by an HMI. The production process, especially for the detergents is complex and involves many parameters and variables, which can manually be controlled through the HMI. The machines require and are sold with training, offered to operators and technicians.

Customers

Their clients are producers in the tobacco, detergents, and food packaging industry. In each sector, there have both small and the largest organizations as clients. Due to variance in clients' organizational and technological maturity, each customer journey is different. Smaller companies are often looking to buy complete solutions, as they often lack knowledge about the building and production process. While larger clients often have their R&D departments with engineers and experience and are more likely to get involved in the research and development stages. Clients can get into a joined development agreement where the designing of the machine is done in collaboration. Another observed difference is machine handling and maintenance. After the SAT (Site Acceptance Test) and the personnel training, smaller companies would often run until breakdown and then contact the case study company, while larger organizations try to root cause issues from a much earlier stage. In addition, due to the nature of the work and the environment, operators will often change monthly if not weekly, while new training will not be purchased for them. This can be seen throughout most of their clients. However more structured and experienced customers would manage to keep and teach their knowledge to new personnel. As an effect, generally the case sturdy company does not have control or overview of how and by whom their machines are run. This can reflect in the perceived image the clients have towards the quality of the machines, as they would assume the blame to the machine's design, and not to their handling and use. The difference in maturity and organizational structure is also reflected in the willingness and time for clients to integrate new solutions, like data monitoring, continuous improvement, and problem-solving software. Furthermore, large organizations are supporting and pushing for the development of new technological solutions like data monitoring, automation, and predictive maintenance.

Business and technological developments

In the last years, the company has made significant investments in research, development, and integration of data gathering, vision, automation, and most recently servitization. Their drivers are a mixture of external and internal, the former coming from the technological push from Industry 4.0 and clients looking for products and solutions catering to this, and the latter from their desire to stay relevant and competitive in the market. As a result, in the last years, they have started a data department, developing their data monitoring software, which currently is used internally, but also offered to clients. In addition, vision and artificial intelligence (AI) recognition algorithms have been added to most machines and are still fields of lot of development. In the past they had not offered maintenance and servitization, resulting in a customer journey ending with the machine instalment and SAT. In the last year, they have recognized this gap and are setting up a servitization strategy. In addition, a sister company had been created with a different business model, where instead of machines, the production capacity is being sold. This switch from selling a product to service is also influencing the future strategic models of the case study company.

Design and manufacturing process

They are two main types of development projects- external, coming from clients, and internal, driven by the company itself. Both will be described, as an HMI can be part of each project type. An external/ client project begins with a request from a client, while internal projects are initiated by employees based on their ideas, predictions, and observations to improve the portfolio and products. An example of an external project is when a company comes and asks for a new production machine, which they need to develop. An example of an internal project would be the Data Monitoring System, which had been initiated by employees with no direct client in mind. Projects begin by being described and approved by the management board. Afterward, depending on the type of project and product they would either- external, enter an R&D stage called conceptualization phase and get a project manager, or portfolio machines enter the industrialization phase, where the machine starts being built. Internal projects depending on their size and type would either get assigned a project manager or someone from the team working on the project (not an official project manager) will take over this role. For the conceptualization phase of new machine development, a project scheme has been made and project managers are encouraged to use it. It has been internally created by mechanical engineers working as project managers, based on popular mechanical engineering product development models. Internal projects do not get assigned project managers and are not encouraged to follow this model, especially if the product is software based. During the industrialization phase, multiple teams work together on the project- mechanical engineering, PLC programmers, HMI programmers, data and sensor engineers, documentation, and commissioning engineers. Once the machine is built, a FAT (Factory Acceptance Test) test gets assigned and if it passes, then training of employees begins and the machine gets shipped. In addition, machine manuals for maintenance and use are created. After a successful SAT, the client has the manuals, trained personnel, and a working machine. However, it is observed in multiple clients that during the first 2 months, there are a lot of problems with running the machines, after which usually the number declines over time. There are rarely client check-ups performed. Usually, contact will be initiated by the clients, when they have a problem. Internal projects tend to be smaller and carried out completely by the same group of people. Machines rarely get updates, since if a client has a machine from years ago and wants new ones, they already have the knowledge for the old machine, and therefore only slight updates are performed. Unlike machines, internal projects get updates frequently, as the departments and people working on them, can easily initiate a new project to make their product better.

Observed Issues

During interviews with employees discrepancies between how the development processes should be carried out and how they are carried out, in reality, were found. Many of these differences were recognized as causing issues and according to the employees, need to be changed. The interviewed employees are from various backgrounds and work in different stages and parts of machine development.

The interviews with employees were conducted and analysed using the VOC methodology. The verbatims from the employees are clustered in statements, which have been kept as close to the original, without making assumptions or suggesting improvements. These statements have been grouped into six main categories for expressed observations, wants, improvements, or issues mentioned by the employees themselves about the current state of product development and organizational structure. The information is presented in a table with the corresponding statements, the people who have made them, and the corresponding number of verbatims in table 6.

The purpose of the research is to investigate what employees currently see as challenging and have recognized as a need within their existing development process. Compared to the identified framework requirements, it can be seen in table 6, all of them have been mentioned as important aspects of successful technological development by the employees. Incorporating the end user, validating the customer's needs, gathering information, and fitting to the vision and values of the company are all discussed in the analysed frameworks. While the guidelines proposed by ILO and IEA [52] highlight the need for systematic documentation. As it is necessary for the proper functioning of any organization and should contain the overall system description and in the case of product development it can serve as the method for achieving the rest of the mentioned needs [58].

The Need	Description	Interviewees Role	N. verbatims
Need to incorporate the end user	The requirements and specifications are defined at the beginning of the conceptualization phase. However, usually, there will be an emphasis on the functionality building and testing in the design of experiments (DOE) stages. While the rest of the design limitations, specifications, and goals will be neglected- usability, service, maintenance, and safety. The end customer currently is not considered in the design. This means that once the concept is developed, the neglected aspects will have to be included in an already	R&D Manager 2x Project Managers 3x Mechanical Engineers Lead Documentation and Training	12

	existing concept. In addition, the representatives from the clients, are often the not end users, so their wishes and requirements for the design do not reflect the end users. Although previous projects involving the end users have proven to be successful, some engineers are hesitant to work with clients.		
	During visits to clients' sites, company employees would talk to operators and notice that their experience with the machines is different from the one reported by their chief of operations. In addition, when talking to operators would often ask why the machines are designed in such a way.	Project Manager Mechanical Engineer	2
	Although client visits are not currently done frequently, it is recognized how valuable they are. This way the company can also familiarize itself with the way operators actually use the machines. However, some clients are more hesitant to share information with outside companies. In addition according to a sister company for production monitoring software's operations director, the main problems in the production come from the operators and their usage of the machines.	Project Manager Operations Director of a Sister Company for Production Monitoring Software	4
	Training is only given to technicians and operators and they are mainly the people who know what the functions of the HMI are. While the HMI has functions and features which are aimed at managers and/or continuous improvement engineers and not only operators. There is a brief description of them in the manual, however, that is also not readily read outside of technicians. This leaves many of the capabilities in the HMI unused. As many of the functions are interconnected, this could limit the user experience of the machines, e.g. shift scheduling.	Client company - Continuous Improvements Engineer Client company – Operations Director Lead Documentation and Training	4
	Continuous Improvement Engineers working within the company have observed that since the machines are designed only based on the URS (User Requirement Specification) provided by the client, the design is only focused on the final production product, and not on the users and the environment. They emphasize that it is important that the machines are designed from a user perspective, with the early equipment pillar in mind.	2x Continuous Improvements Engineers	8
Need to validate customer's needs	Some of the new development ideas proposed by employees are not based or validated with the customers' needs. They are based on the employees' interests in the technology field and on fixing and optimizing existing issues. If the developed solution cannot meet customers' needs and expectations, they will not show interest in it. The R&D Manager tries to predict customer needs and he will try to validate the need with the customer and through Sales, before perusing the project, however, he is one of the few employees who do that.	Lead Software Engineer Project Manager R&D Manager Data engineer	8
	The current project application process involves filling in a technological development form. As part of it, the employee needs to discuss the impact, motivation, and description of the project. Based on this form the project will be assessed by the management. Formulating and acquiring the needed information for such documentation is not a strength of most engineers. This could lead to projects which are not properly augmented and validated. Moreover, if the process is very dreaded the engineers might not want to go through it and will potential not file development ideas. This could lead to serious consequences as the development matrix is based on the input of employees.	Project Manager R&D Manager Lead Data Engineer	4
	Smaller internal projects, especially software-based ones, do not get external project managers (PM) and the employees responsible for the project are also PMs. They however are not aware of the existing project structure and carry out projects with their knowledge. This usually would be using the SCRUM method. An obstacle with this way of working is that these projects are left unattended and they need to do their validation, which could often be biased. In addition, there is a lack of focus on the customer, as employees do not emphasize the product owner role. Usually, these projects are time-focused (hours of work), instead of goal or value focused. This in combination with having no clear project structure and a product owner, leads to reiteration and improvements of existing solutions, as they are an obvious 'goal' for additional work hours. As the PMs of such internal projects are engineers, they spend a lot of their time with organizational, managerial, and administrative work, which are not their strong suit, instead of working on engineering solutions.	Lead Data Engineer Project Manager Lead Software Engineer	14
Need to gather information	There is a lack of communication between the sales department and the engineers. This reflects in the communication of customer needs. Sales lack technical knowledge and need the help of engineers. On the other hand,	R&D Manager	5

	when the engineers are working on a project, they rarely communicate with Sales on translating and validating the customer's wishes. Sales have the best overview of what the customer wants, but without the proper technical knowledge, it is hard for them to translate the information into a technical solution. The R&D Manager keeps Sales updated on his projects, however, most project managers do not do that.	Business Development and Account manager (Detergents)	
	The responsibility for identifying the customer's needs is not clear and not actively pursued. It is perceived that Sales should be responsible for it, however, engineers are often asked to give insights into the customers' wants and needs, which is not their expertise. The need identification should be a multidisciplinary process, done together with Sales and technical representatives. This is especially important in the beginning stages of a project when its direction needs to be defined. Sales need to be the contact point between the project managers and the clients, as this way they can keep an overview and negotiate properly with the clients. However, many project managers bypass Sales and communicate directly with the clients.	Lead Software engineer Project Manager R&D Manager Lead Data Engineer; Service Manager	8
	Projects carried out by the company require multidisciplinary knowledge, however, they are only executed by mechanical engineers. This means that the research and development done is limited by the scope of their knowledge. In addition, there is a disconnect between research and development, as they are not perceived and done together, but separately and there is no communication between the teams.	R&D Manager 2x Continuous Improvements Engineers	7
	According to multiple employees, there is an internal communication problem. They observe that as projects are multidisciplinary these issues in combination with the lack of documentation present and escalate to great challenges, as communication is a key factor in such projects.	2x Project Managers Lead Software Engineer Continuous Improvements Engineer	4
Need for systematic documentation	The documentation of activities and design rationale is not scheduled as part of the project time. This affects many aspects of the design process, as the projects are multi-disciplinary and involve sharing and building upon the information. This is a problem for manual making, for data and sensoring, for HMI and PLM, but also decision traceability. Manual making and the gathering of information becomes a long and hard process. For example, employees may perform key activities on the machine (such as a changeover) which are not documented, which makes it hard for the documentation department to later describe them in the manuals. For data and sensors, a PFME can help by outlining where and what sensors are needed at an early stage with adequate rationale behind it.	Commissioning Engineer Marketing Manager Lead Documentation and Training Sales Manager Lead Data Engineer Lead Software Engineer	7
Need to fit to vision and values	When a project inquiry comes (both external and internal) it needs to be approved by the management team. They consider its alignment to the companies' strategic goals, its feasibility as well as the ownership of the project/technology.	Service Manager Business Development and Account manager (Detergents)	3
	In addition to the fact that machines are only focused on the final production product, and not on the users, the design process does not consider the company's strategic vision, which is currently servitization. This is affecting the internal continuous improvement engineers, as they are lacking functionalities and sensors, and information required for their work.	2x Continuous Improvements Engineers	8

Table 6. Observed issues and need for improvements within the current production process from employees in case study company

5.2 Application of framework

The application of the framework to a real-life project requires adaptations, which depend on the organization, the goal of the project, and the people responsible for it. This section will discuss the specific changes and ways in which the proposed framework is used during the case study. The framework will be used for a redesign of an existing HMI- named HMI4. The goal set by the case study company for the new HMI is to provide better machine usability and cater to their and their clients' future needs. The motivation for these objectives comes from the observed issues regarding the drop in OEE after the SATs. This according to them is due to a multitude of reasons, including the production process, the environment, the personnel, and the client organization, but also the machine user-friendliness. In addition, it is recognized that the machines do not support the new continuous improvement strategies of the case study company and also lack support for the digitalization switch happening with their clients. As the framework is applicable for HMIs, the case study company has decided that the objective of this redesign project should be aimed only at improving the user-friendliness and recognizing ways of supporting the needs of the CIE (Continuous Improvement Engineer) and the client companies.

Scope of the project

First, a better definition of the objective and the scope of the project has been created together with the employees. The initial scope of the project is limited to the HMI development team, however, the company is open to involving other teams. This is due to the fact that the organization is interested in further expanding its Industry 4.0 and servitization strategy and recognizes the HMI as a vital part of it. However, the framework application will be set within the boundaries of the software HMI team. There are two operating HMIs currently- HMI2.5 and HMI4. HMI2.5 is the most widely installed and used HMI and therefore a large amount of the conducted research is based on it. HMI4 has similar functionalities and has already integrated improvements on issues observed in HMI2.5. It is the HMI that is currently being sold with new machines, however, at the moment, it had been implemented only at a small number of clients. The suggested improvements will be made for HMI4, however, both of them will be analysed.

Framework application

Following the framework, a current state of the system is done. For this HMI it encompasses the whole lifecycle of a machine, as decisions influencing the final design begin at the initial stages of a project. As part of the lifecycle map, all of the actors and their influences on the HMI have been identified. This way the limitations and possibilities of the software development team are known. Furthermore, a detailed analysis of how HMI-related projects are conducted within the team has been made, aiming to recognize how their process is affecting the final design. During the creation of the lifecycle map, the use scenarios have been described through documented interviews using the VOC methodology, which will be discussed in further detail in the next section and through field visits and observations. To get a comprehensive view of the HMI's use a functionally analysis has been made of both HMIs. The use scenarios have been made for HMI2.5 as at the time of the case study it has been the only HMI in operation, therefore its functionality analysis provides insights into the technical possibilities of the system and it can be observed how they affect the use of the machine. While HMI4's analysis will serve as a base for the proposed solutions. As one of the objectives for the redesign is usability, the HMIs have been additionally assessed using Nielsen's Usability Heuristics Rules, which are widely used for design interfaces [59][60]. As the original heuristics rules were created in 1994, a paper by Gronollers [60] made a reassessment of them and added a set of questions for UI/UX usability based on Nielsen's work. They will be used to evaluate the HMIs based on the functionality analysis. A PACA/T (People, activities, context, artefacts/technology) analysis had been performed to enhance the understanding of the use scenarios. PACA is used in interaction design as it examines the relationship between the user, the technology, and the environment [61]. This method is useful, as the HMIs have multiple use scenarios in different environments. The use scenarios are identified using the lifecycle map and the information for them is obtained using the VOC, observations, and field visits. To establish the current state of Industry 4.0 technology, use and its potential applications, VOC interviews, and document reviews were conducted and analysed based on Dalmarco et al. [1] nine key technologies. Lastly, all of the conducted VOC interviews have been analysed and clustered, resulting in a list of needs, wants, and aversions for the HMIs.

Interviews

During the research phase of the case study 27 people, 35 interviews, and two customer field visits were conducted, with the majority of the interviewees being from the case study company. The employee interviews were held individually, as it has been observed that people are more likely to bring up sensitive topics during individual interviews, than in group settings [62]. In addition, in a paper by Morrison [63] about employee voice behaviour- the likeliness and reasons why employees speak up in work environment, he discusses that one of the inhibitors for employees to speak up is the probability of negative personal outcomes. He also highlights the concern of not wanting to be viewed negatively by others, or damage a relationship and the fear of retaliation. Another factor influencing the outcomes of the interviews is the interviewer. In the case of this thesis, it is the author - an industrial design Master's student from the University of Twente, seen as an external person with a neutral agenda. This furthermore lowers the perceived risk associated with speaking up and enforces a perceived safety [63]. As there is a whole field dedicated to employees voicing their opinion at the workplace, with a multitude of inhibitors for them to do so, it can be presumed that people are likely to share and talk about their work with people outside of it. Unlike outsiders like friends and family, the interviewer had very well familiarized themselves with the company structure, products, and ongoing work from existing documentation and verbal conversations. This in combination with their external neutrality gives employees the predisposition to freely share their experiences, both positive and negative and to also give suggestions and recommendations as they see best suited. This is different from having discussions with supervisors or HR, as with the former as discussed by Morrison [63] employees are hesitant to speak up to superior figures, while the latter are not always as familiar with the day-to-day work life and ongoing projects of the employees. The format of the interviews is a structured informal discussion, where the people were sent in advance topics of discussion, which were consistent throughout all interviews. During the actual conversation, main questions on each topic were prepared, however, deviations happened and adaptations were needed, as each employee had their own experiences and knowledge in specific domains and projects. A key aspect of VOC interviews is that they are not focused on solutions, but rather on the needs, wants, and aversions of the user [56]. Therefore, unless the person has not pointed out a solution themselves, they were not asked for one. Moreover, when a solution was given the discussion was navigated towards defining and discovering the problem, as well as why this particular solution is proposed. By doing so, when analysing the VOC more opportunities for generating solutions will be possible and creative restrictions will be prevented. The interviews are recorded, after which all of the verbatims are extracted from them. This way it is ensured that the words of the employees are not interpreted and the information does not get lost or changed. The verbatims are categorized by date, name, company, department, position, and stage of the lifecycle they belong to and are afterward clustered.

6. Evaluation of framework

This chapter will present the evaluation of the framework. The first section will look at the results from the case study, followed by an evaluation of these results compared to the requirements of the framework. And lastly, suggestions and improvements will be given.

6.1 Case study results

This chapter will discuss the results from the application of the framework. The point of the case study is to showcase the capability of the framework to capture the aforementioned required aspects, as they are needed for a comprehensive understanding of the factors influencing the design of a new HMI within Industry 4.0 context. The focus of the text will be on the issues and observations made while conducting the case study. While the results and the detailed work that had been performed will be available in Appendix B.

HMI Industry 4.0 application

Together with employees an assessment of the Industry 4.0 technological state of had been created using Table 1 and Table 4. The goal of this analysis is to generate the technological foundation and needs that the future HMI design will be based on. The results represent the employees' understanding of the existing and strategic visions of how these I4.0 technologies apply within their company and to the HMIs. The result of this assessment is a table with two columns- one for the how and if the technology is currently implemented and the second is the existing and proposed future strategic applications and their implications for the HMI design. During this analysis, multiple weaknesses were noticed. The first one is a lack of knowledge from the employees on Industry 4.0 technologies and their possibilities. As this had been expected, Table 4 had been created to serve as a base for the type of technologies and their possible HMI effects. However, it has been noticed that the employees needed additional explanation of what these technologies entail. Because of this, it had been hard for them to assess how the company is currently implementing them and even further to suggest the design impact they could have on HMIs. It is important to note that this limitation could be case-specific, and companies that wish to apply this framework could have a wider Industry 4.0 knowledge. An additional limitation of this research was the individual interview format. Its first impact is that the employees were limited to their understanding of the current state, which creates a need for validating the information. While the second is connected to their capability to generate HMI-related applications, as discussing the ideas with multiple people, could create more ideas. Nevertheless, this method does provide information regarding the current state of I4.0 technologies and does encourage employees to think about if and how they are present in the company. Even further the employees are not only pushed to consider the technological and strategic influences on the HMI's design, but also how the HMIs can facilitate and cater to those changes.

Lifecycle map

A lifecycle map had been created using multiple channels for acquiring information- VOC, PACA analysis, field visits, and observations. The life cycle map is a literal map from the machine's acquisition, designing, building, use, and end of life. It contains information about the actors, processes, and activities taking place at each of these stages and their influence on the HMI's design. For this case study, the map has been visualized as a table with each stage containing its attributes. As this information was not available and documented in the company, the research required interviewees with employees. Once again the interviews had been conducted individually with the goal of getting a deeper understanding of each stage and the role of the different employees in them. However, as the lifecycle contains a lot of stages and actors, individual interviews have proven to be very time-consuming, as 30 employees had been interviewed- both external (client) and internal (company). Nevertheless, once created this map can be used for identifying influences for future redesigns, which as the HMI is a software-based product happen often. The map also provides insights into the human interactions, and organizational and production processes of both internal and external users. One of the big benefits of having individual conversations is the amount of information that had been obtained, as the employees have shared many of their own opinions, aversions, likes, dislikes, and needs regarding the HMI and its use. This information had been documented and analysed using the VOC methodology and can provide a base for the requirements of the future HMI design. In the case study, this was one of the most fruitful methods and it yielded a lot of the system's needs. Another result from the lifecycle analysis is the assessment of the development processes of the design team. This is beneficial as often designers are not critical of the workflow they have already established. For example, in the case study it had been observed that the team was using the SCRUM method, however, admitted that they were omitting the product owner role. Although aware of this information, they did not realize the impact it was having on their final products and now they can change it for their future projects. Furthermore, to enrich the map a PACA analysis had been conducted. The aim of which is to identify and describe the HMI's use through its relevant actors, their activities, context, and artefacts. The information for this analysis had been acquired through observations of the production process and use of the HMIs, field visits, and the VOC. The PACA analysis is a useful method, as it forces the designer to consider all of the contexts, users, and their interactions, which is especially important for HMIs. One of the benefits and needs of a lifecycle map is to identify all of the influencings and affected aspects for a specific design goal- the project scope. As discussed in the framework chapter, through the lifecycle map the scope can be reassessed as new information might become available to the design team. However, if it is known that the design scope cannot change and the team is strictly limited within a known set of boundaries, then the lifecycle map can also be limited to that.

Functionality analysis

The case study project is a redesign of an existing HMI, therefore as part of having a comprehensive current state a functionality analysis was created. The functionality analysis can serve as a map of what is already possible and how. The type of functional analysis that was performed was in line with one of the goals of the redesign- improved usability. As functionalities can be mapped in many different ways, the chosen one must correspond with what the data will be used for in the future. What had been done for the case study is a mapping of the different windows/tabs and the possible actions and features within them. It is documented in Excel and next to each action the team can add comments and descriptions about the function, its purpose, observed issues, or notes. This type of analysis was possible as the HMIs are not very complex or big and most of the features can be executed only one way. However, two versions of the software had to be analysed, which had proven to be time-consuming. Nevertheless, this information was not available and is of value to the design team as it can serve as a base for other types of analysis, for tractability, for future redesigns, workshops, and other departments requiring it-like manual making. For the case study, it was used to evaluate usability through the HMIs using Nielsen's Usability Heuristics Rules. Doing this kind of evaluation through established methodologies can save time and resources as usability issues can be discovered before user-testing. Both of these activities force the design team to take a critical look at the design and focus on the usability, efficiency, tractability, and safety of the software. If the project is not a redesign, then the heuristic rules can be used as guidelines for building the software. It is important to note that if the HMIs are very complex, then the team will need to reconsider what they need to know about the software, based on the project's objective and change the type of functionality analysis accordingly.

6.2 Evaluation of framework requirements

In the theoretical background chapter requirements for the framework were created. As these factors are focused on the results from the framework's application, rather than the structure of the framework itself, its success can be assessed through how well the required aspects are represented in the case study results. This section will only discuss how well each aspect is represented, while suggestions and improvements on the framework will be presented afterward.

Human aspect

The human factor is present in the framework in two ways- considering the users and their specific needs; and considering the human cognitive limitations and their effects on framework's application. Both of which are represented through the selected methodologies for acquiring information. The methodologies get the right information about the users, as well as guide the design team to consider the important factors. Unlike the other aspects, the human factor is part of in all other requirements, as all of them incorporate people. The PACA analysis and the VOC show through the lifecycle map how people interact with manufacturing processes and technologies, the effects people have on the organizational processes, and what people like and dislike about the whole system. The Heuristic Rules evaluation and field visits also give insights into the human aspect of HMI usability. The VOC is one of the most powerful human-factor-focused methods for building needs and requirements, as it creates a map of the voice of the customer. In addition, using this method for acquiring information forces the design team to talk to people instead of assuming for them, which as mentioned in the theory chapter is a common issue.

Organizational structure and values

The framework examines the effects of the organizational structure mainly through the lifecycle model. Where the workflows of the different departments are described together with the actors and the effects they have on the HMI. The proposed methods for capturing the organizational structure are through verbal interviews and document analysis. The value of the lifecycle map is that it examines only the structures relevant to the HMI design. In addition, it forces the designers to consider both the organizational structures internally and at clients, which at the case study company was not done. However, the values of the organization were not identified through the use of the framework. One reason for this could be related to the case study company, as there were no documentation regarding this. Moreover, multiple people were interviewed about them, but regardless there was no clear answer that could have been used in the results. Another reason is that no specific method was proposed for assessing and gathering this information. The level of depth that the lifecycle map can provide the decision makers regarding the organizational structures should be adequate for them to identify the necessary influences and needs. However, an additional method or assessment could be added to the framework for acquiring and translating the company's values.

Manufacturing processes

The manufacturing processes are at the base of HMIs, as through them the machines are controlled. The framework offers a few ways of observing them and their effects. First of all, an HMI manufacturing company will likely be using a version of the software for many different types of machines, therefore it will have a base design and will change accordingly. In the case study, the framework has been used on the base software, therefore no examinations of a specific machine and its processes have been made. However, through the lifecycle map and the PACA analysis, the interactions and the workflow that the operators and other users have with the HMIs and the machines are analysed. The most amount of information was obtained through the VOC interviews and field visits at client companies, where the operators' work was observed and documented. The interviews allow the workers to share their frustrations, suggestions, and sometimes modifications providing great insights on the preferred and intuitive use of the machines and HMIs. The needed level of detail for the manufacturing processes will depend on the scope of the project. If it is possible to make adjustments to the manufacturing processes and the design of the machine, then more emphasis should be put on that part. Currently, the PACA analysis focuses on the workflow of the operators and other users with and around the machine, but no method is provided for capturing the machine manufacturing processes.

Technologies

The framework describes the technological aspect in two ways- through the Industry 4.0 assessment and through the PACA analysis, both of which are different. The I4.0 assessment gives an idea of what are possible solutions for the future HMI design, while the PACA gives insights on what technologies are available within the use scenarios. The I4.0 assessment has limitations as it only provides a table where the design team needs to understand the implications of that technology in their organization and then identify how it could be applied for their HMI. Without the proper expertise, this can give a limited idea of possible design directions, how realistic they are, and how they can be executed. However, it could be argued that companies with little prior knowledge and experience with I4.0 technologies will slowly integrate them into their organization, in which case the I4.0 assessment might be a good start for them to see what is available. While more advanced companies can use the tables as a checklist and compare if there are new ways they can apply their existing technologies. Nevertheless, a more detailed method for I4.0 assessment would be a beneficial addition to the framework.

Practical guidelines

The framework is supplemented with methods for structuring and acquiring information during its application. As seen in the text above, all topics except for one- company values, are in various degrees described through them. The types of methodologies are HF/E focused, as the human aspect is implemented throughout all other factors. Out of all the suggested methods, the VOC and the PACA analysis seem to be the most impactful and beneficial. As it can be seen they give insights on almost all of the topics and do so in a systematic and HF/E-focused way. Most of the other suggested methods are freer and left for interpretation, which is also why their value can be questioned. All of them do force the design team to consider the required aspects, to which end they could be called successful. However, as said previously the framework does require additional methods, as the current ones have limitations.

6.3 Suggestions and further research

During the case study and the evaluation of the framework, multiple shortcomings were observed. From the evaluation, it can be seen that most of the information is acquired through individual interviews and although for some specific situations this is useful, as discussed in the framework application chapter, it is also very time-consuming. It furthermore misses on the collaborative and brainstorming aspect that comes with group interviews and workshops. Workshops would be a great addition to the framework for multiple reasons. First of all, during the I4.0 assessment if employees from different departments come together and are presented with the same assessment tables, with their combined expertise they might generate a lot more accurate ideas, faster. Furthermore, through caring out multiple individual interviews, the acquired information can only be verified, contradicted, or built up (which still requires validation). Whereas in workshops people can expand and collaborate on ideas and immediately come to a common ground. Workshops would be also useful for the lifecycle map creation, as instead of repeating the same process and questions with people from different departments, representatives can be gathered and provide at the same time the needed information and verify the rest of the stages. Workshops would significantly help with another observed issue- the duration of the framework application. Keeping in mind that the HMI is a software-based product and its development is mostly scheduled as part of a project, the timespan for the framework currently is too long- the case study was conducted over 6 months. Although this duration could be explained through various reasons like the number of individual interviews that were carried out, as well as the nature of the case study for a master thesis. As a whole, the framework currently does not consider time-management and project management as an element and only provides a general structure of stages that need to be executed, with limited sequential order or guidance. In addition, more methodologies are needed to better capture the values of the company, the machine manufacturing process, and the Industry 4.0 technological state. As the current chosen methods work together providing insights on multiple levels and building on each other, it will be beneficial if the future additions do so as well. It will be good if the new methodologies are applicable in a workshop setting, as well as provide systematic documentation, and are HF-focused. During the case study, it became apparent that there are two big scenarios for using the framework- for a first design and a redesign. The two cases differ, as with a redesign the goal of the current state is to model and observe a system that already exists and identify its needs, issues, and areas of improvement. Whereas with a first design there is no established status quo from which to start observing needs. Therefore, it can be suggested that the framework has two use scenarios- for redesign and design. This is where another limitation of the framework has been discovered. As it is built upon academic literature, the framework does not include conducting and analysing the market sector- the competitors. In reality, many manufacturing companies would also have access to commercial HMI software and will have the ability to compare and analyse what is possible and available. A market analysis will be beneficial for both design and redesign, as it will give insights to the design team on exciting innovations, and possibly Industry 4.0 technological applications. Lastly, the framework does not consider the financial aspect. Although cost can be part of the 'design objective', there are no methods or even mentions of finance within the framework. In a summary, the framework should integrate more methodologies regarding company values, Industry 4.0 technology, the financial aspect, and market research. In addition, it will be recommended for the VOC to be conducted in workshops or group settings. And the whole framework can facilitate two design streams with their methodologies- one for redesign and one for design.

7. Discussion and conclusion

7.1 Theoretical contribution

The thesis proposes a new framework for the beginning stage of HMI development processes. The creation of the framework is following the design science research paradigm. Through the designing and evaluating of the artefact (framework), new knowledge and understanding of the problem are contributed. First, the process of creating the framework- the theoretical background and the framework requirements gives insights into which factors are important for HMI development. The framework itself is unique in the fact that it is specifically targeted toward HMIs. Moreover, it provides methodologies, which have been assessed and evaluated through the case study. During that time another unique aspect of the framework was found useful - the re-evaluation of the current state scope. This particular element is missing in other works, however, in the real-life scenario, it had proven to be very beneficial to the project. This is distinctive of the focus of the framework- HMIs, as the influence of their design and use scenarios, span throughout the lifecycle of a whole machine with different teams, and possibly companies. Therefore, after having a full picture of all the relevant factors, it is important to adjust the work scope and objective if needed. The case study's evaluation also reveals gaps requiring additional research as discussed in the previous chapter. The framework is focused on the human-factor as its important became clear from literature. The trend for incorporating people into the manufacturing planning and work strategies will increase even further, as it can be seen at the core of theories like Industry 5.0 (I5.0) Although it still a new topic with divisive definition, Industry 5.0 is focused on leveraging the human factor in every aspect, instated of turning to technology for creating solutions and value [64]. The central point of I5.0 is the human both from the user perspective with mass customization and manufacturing with recognizing the value of the human and designing for collaborative production [65]. Therefore, as the central point of the framework is the HF it can be seen as a step towards the future of the industry.

7.2 Practical contribution

The goal of the framework is to be used in real-life scenarios. Therefore, one of the requirements for it is to be practice-oriented and supplement and guide the users with methods of application. Through the case study and its evaluation, it can be seen that multiple methods for obtaining and systematically documenting information have been observed as useful like- creating a lifecycle map, VOC methodology, and PACA analysis. Moreover, in the suggestions and further research section more practical ways of improving the framework have been identified and can serve as a starting point for future research.

7.3 Conclusion

For successful development of a design or redesign of a new HMI system within Industry 4.0 era, five main elements have been identified as necessary. In this thesis, the elements- the human factor, the organizational structure and values, the operational and manufacturing processes, the technologies, and practical guidelines for application have been combined in a framework accompanied with use methodologies. The framework has been tested in a single case study for an HMI redesign in a Dutch machine manufacturing company and the results have been evaluated in two ways. First, it was checked if all the required elements have been identified through the application of the framework, where it was found that all factors but one- the values of the company, were discussed. And second, the usefulness and fitness of the proposed methods and the structure of the framework were assessed, from where it was observed that the framework's stages are fitting to an HMI development. However further research is needed on supplementary methodologies. In a conclusion, the framework proposes a good initial foundation for the research phase of HMI development, however as the usefulness of the additional methodologies can be only tested through case studies, further research is needed.

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Appendix A

VOC interviews

The Voice of the Customer (VOC) is a methodology used to transform qualitative customer expectations, preferences and aversions into quantitative system requirements which can be used within engineering fields. The goal of the VOC is to incorporate the customer in the design decisions at the earliest stage and to do so in a systematic and easy to trace back way. This document will serve as a guide how to successfully apply the VOC methodology. The VOC is an iterative process, meaning more information can be added with time. However, it should be done in a systematic way, to prevent discrepancies in the data and results. Therefore, each stage will be described in detail with steps and reasoning, so that the VOC can be performed by many people with different set of knowledge and skills.

The importance of the customer

In order to properly apply the VOC methodology, it is vital to understand the important of the customer and why they are the base of any product. A product by definition is anything that can be offered to a market to satisfy the desire or need of a customer [1]. Therefore, a production machine is a product, with the main goal to meet and satisfy the needs and desires of customers. The design of the production machines and any other products or services made by an organization should begin with the customer and they should be kept in-mind throughout the entire process. This way the end-result would satisfy the user and in return manufacturing organization will leave a positive salience in their mind.

Conducting Interviews

The VOC begins with the actual "voice of the customer" meaning obtaining data about the customers' expectations, preferences and aversions. Although this can be achieved through multiple ways like surveys, social media, emails, feedback forms and more, for the nature of the framework interviews would be best suited. The first reason being that manufacturing companies tend to have less and known clients, unlike with a mass produced product, with millions of anonymous consumers. And second manufacturing products are vastly complex and simply any other form of acquiring information would most likely miss a lot of details.

Structuring the interview

One important aspect of the VOC interviews is consistency. Although it is natural to have deviations in the interviews, the same main topics should always be discussed. These topics should be identified by the team responsible for the VOC. There are two types of interviews, the first is exploratory, where the design team is still acquiring information to build the current state and validate their work. While the second is validating the need from the set design objective. Without a need, there is no product, therefore the identification of the need is should be the main point of the interview. It is possible that the customer is not aware of their need, let alone aware of a solution. This is why it is useful to go through the user experience journey of the client for TDC's products and together with the customer and guide them to identify areas of problems, wants and wishes. On the opposite end a customer might be interested in a solution due to its attractiveness, like data monitoring, or digital twin, but they might not have the actual need, or resources to facilitate this solution. Therefore, there are multiple topics in a VOC interview which are generally recommended. This is only one type of interview structure and it is possible that for certain product/problems there are other formats which will be more suitable, however creating a base or profile for the type of interviewee (and client company) is strongly suggested.

Company and interviewee profile

The company profiles should give a good idea about what the company is, what is their size, their industry, product portfolio, their main activity, they organizational structure and their technological maturity. This should give context to the interview and create a base. It will also be useful for clustering and analysis, to see if similar companies have similar needs, aversions and preferences. In addition, if a correlation is identified then target companies can be more easily found in the future. It is very likely for the same need to be observed in different types of companies, meaning the type of company will not directly influence if a need is present or not. However, knowing the differences in companies might help later when the solution is developed, to segment the market and create targeted solutions. For example, a rather small, not very structured company, with limited resources, although sharing the same problems and needs will not benefit from the same solutions as a big cooperation.
In addition to creating a company profile an interviewee profile will be beneficial in similar ways as it will provide context to their answers.

Current way of working

It is important to get an understanding of what the current state of the customer is. By the customer describing the relevant activities, TDC will get insides on how currently the works is being done and see if there are any explicit or implicit needs. Here the customer is encouraged to talk about any expectations, preferences and aversions they have within their way of working and the discussion can get detailed.

Example: A new data monitoring solution.

A data monitoring solution might have many applications and solve multiple needs. It is a tool that could be used at all operational levels in a company. This is way, for a good understanding of all activities a lot of information will be needed for the current state –input from operators; quality managers; production managers; continuous improvement engineers; service; etc. If for example the manufacturing company is already aware that they want the tool to be used by management then they could narrow the discussion topics to these activities.

Topics which might be brought up then are- exact work flow, shift management, production and quality management, production documentation, current data utilization, observed problems and identified needs, data missing and/or using the most, etc.

Desired state

Although the majority of the expectations, preferences and aversions will be discussed in the current way of working section, as essentially the customer is a company, they unlike individual consumers most likely have a strategy and a preferred state for the future. As TDC's products can be viewed as an investment, it is important that the they are in line with the future vision of the client companies. In addition, many of the employee's might have insights on how they work could be better and more efficient. Therefore, there should be questions regarding the future strategy of the company, as well as asking for wishes and preferences that the users of the potential solution might have.

Validation

If a specific solution is already being worked on, then it is possible at the end of the interview, to validate with the customer if they would be interested in this product/service. From a business perspective this gives the impression to the customer that the solution is built to fit to their specific needs and can amplify their desire to make a purchase. This is especially true if the interviewees believe that the product can be a solution to their problems.

Selecting the people

The outcome of the interviews is widely dependent on the people present. This is the case both for people from TDC and the customer. Having the right people with the right knowledge can drive the discussions much further. How to select the correct people:

Ask what is the product/service of matter and identify the areas of expertise needed.

Example: A new data monitoring solution.

In the scenario where an organization is developing a new data monitoring solution, the design process should begin with the VOC, this way the development of the new product will cater specifically for the customer's needs. In scheduled interviews the people present from the organization should have the technical background of how data monitoring works as well as what are the technical limitations. On the other hand, there should be a person who is aware of all of organizational, operational and production process aspects of the customer and the organization's own product. By having knowledge in both domains the interviewer(s) can freely navigate the discussion and both get detailed and keep a big overview of the topic. For example, if only a data engineer is present, then the conversation is much more likely to skewer in deeply technical topics like –data protocols and hardware and miss out on understanding why exactly does this client want data monitoring and do they really, how will the data be used, by who and with what experience? From the customer there should be people with knowledge about the state of their technology, their data strategy, human resources available, current data use, work operation struggles, needs and wants.

Communicating the intentions of the interview

Once the intentions of the interview are known and the areas of expertise are clear, it is matters of finding the correct people. In the manufacturing organization this should be done internally, as it is suggested that people know each other and their skills. For the client it will have to be clearly communicated what the topics of discussions will be and knowledge in what areas will be needed.

Preparing for the interview

The goal of a VOC interview is to get the unbiased opinions and thoughts from the customer about their needs, wants, wished and aversions. This is why the phrasing of questions plays a very important role. There are multiple recommendations on how to avoid direct biasing in the interview [2]:

Use of open-ended questions

The use of open-ended questions allows for more accurate response, as the person is free-forming their answers. Especially in VOC this is of great benefit, as the most amount of information is wanted from the customer. In comparison closed-ended question offers a set of possible answers, which already sets a limitation as solutions are being presented to the customer.

Example: A new data monitoring solution.

Open-ended question: What is your company's vision on data use in the future?

Closed-ended question: Does your company plan on implementing in the future a data monitoring solution?

Not providing solutions and asking "Why?"

In addition to avoiding closed-ended question, it is also a good idea to avoid all solution providing discussions during the interview. The goal of the VOC is to hear what the customer has to say and not to tell the customer what they should be wanting. If a customer talks about an issue they are having, then instead of trying to provide a solution during the interview and asking if that would be helpful, the interviewer should ask why this this a problem at all. Letting the customer describe it themselves, could also lead to them revealing their wants and wishes.

Example: A new data monitoring solution.

Providing solution

Customer: We are currently not analysing our quality control data.

TDC: Great, then if we provided you with a tool which does that, will you be interested?
Customer: Yes, sure/ No, we are not really interested
Asking Why
Customer: We are currently not analysing our quality control data.
TDC: Why are you not doing it?
Customer: We do not have people with data analytic skills.
TDC: Why do you not have such people?
Customer: Because data analysis and acquisition is not part of our current strategy.
Etc….

Careful with summarization

During interviews it is likely that after a long discussion a summary is made of what the customer has said. It is possible while doing that, that the interviewer unthinkingly alters the words of the customer, therefore in such situations it might be best to ask the interviewee to summarize their answer themselves.

Timing of questions and level of detail

The timing of questions and more specifically the shift of topics can also have a great effect on the interview. Although it is advised to go in the prepared order to topics/questions, the interviewer should also follow the natural flow of the conversation. By doing that the interviewee will not have to constantly jump back and forth in topics, possibly forgetting information. By navigating the flow of the discussion the interviewer can let some topics get in greater detail. This however can also happen unwantedly in which case; the topic should be switched as well. In the possibility that the discussion gets irrelevant to the interview, then it is also important that the interviewer steps in and changes the topic to a relevant one.

Documentation

An important aspect of the VOC is the fact that the words of the customer are literal, with no paraphrasing. Therefore, proper recording should be done during the interviews. After which the extraction of verbatims (literal verbal statements) and they categorization should be done.

Recording

Although during interviews there are multiple ways of recording, for most accuracy it is recommended that it is voice recorded. This should be done with the permission of all parties taking part of the interview. In addition to the recording the interviewer(s) can also take notes during the discussion, as it can be helpful to write down new questions, or topics which should be brought up, without interrupting the conversation. Moreover, important facts can be written down, as they can be useful during conversation. In the situation where voice recording is not allowed, then writing the answers during the interview will be an alternative. If writing, it is recommended to stay as literal as possible, with making as little to no changes to the statements. In this case it is possible to ask the interviewee to summarize or repeat especially long answers to a topic. In addition, it will be useful to write the answers with the topics or question they belong to, as it will give more context later.

Verbatims

Once the interview is over it is time for the extraction of verbatims. This will be the foundation of all of future analysis, therefore it should be done with attention. The verbatims are statements made by the customers in which they express expectations, preferences and aversions and they can be both implicit and explicit. It is possible for an answer to contain multiple verbatims, in which case it is suggested that they are separated, even though they might be related to the same topic. It is suggested that for one VOC set of interviews there should be between 200 and 400 verbatims, however this number is an approximation.
Example: A new data monitoring solution.
Expectations
Explicit: I need to have all of the data from the HMI transferred to my computer.
Implicit: The shift reset in the HMI is not used by the operators, and it is hard to analyze the data.
Preferences
Implicit: I don't have currently time to manually transfer all the data from the HMIs to my computer.
Explicit: I would like it if all of the data from the HMI is automatically sent to my computer.
Aversions
Implicit: It is hard for me to analyze all of the HMI files in their current state
Explicit: The operators do not reset their shifts in the HMI, as they find it too complicated.

Categorizing

For ease of analysis and universality it is recommended that the VOC is done in Microsoft Excel. This way the verbatims can be categorized according to their date, interviewee, interviewee position, company, and further categories. These can be decided depending on the project for which the VOC is being conducted. They will also have an influence on the further analysis and clustering which will be done to the verbatims.

Example: A new data monitoring solution.
Reference (Name of interviewee)
Date
Role
Company name
Verbatim
Hardware (related) - this cell can be a yes or no
Software (related) - this cell can be a yes or no

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