LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

School of Engineering Sciences

Department of Industrial Engineering and Management

Innovation and Technology Management

MASTER'S THESIS

REQUIREMENTS DEVELOPMENT FOR THE NEXT GENERATION HUMAN-MACHINE-INTERFACES IN THE PRODUCTION LINES

ABSTRACT

Author: Lassi Uusitalo Title: Requirements development for next generation Human-Machine-Interfaces in production lines Year: 2018 Place: Regensburg, Germany
Master's thesis. Lappeenranta University of Technology 99 pages including 24 figures, 4 tables and 3 Appendices
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Keywords: Human-Machine-Interface, Industry 4.0, digitalization, requirements engineering, design thinking, technology acceptance
Industry 4.0 and digitalization of production lines is a hot topic across several manufacturing industries as companies attempt to gain competitive edge through increased productivity, decreased throughput times and decreased amount of faulty products. In an increasingly complex production environment data plays a key role in manufacturing decisions and gigantic amounts of data is produced every day, which makes managing it increasingly more difficult. Adequate digital tools need to be developed in order to keep up with increasingly competitive environment. This research paper aims to use a combination of requirements engineering and design thinking in order to understand the explicit and underlying needs and challenges production line managers face in their work in order to create an initial list of requirements for next generation Human-Machine-Interfaces. This research paper also investigates the effort expectancy and performance expectancy of potential technologies which could be introduced to support the production line managers in their work and based on those make prioritized list for recommendations of future Human-Machine-Interface development projects.

TIIVISTELMÄ

Tekijä: Lassi Uusitalo

Työn nimi: Requirements development for next generation Human-Machine-Interfaces

Vuosi: 2018

Paikka: Regensburg, Saksa

Diplomityö. Lappeenranta University of Technology

99 sivua mukaan lukien 24 kuvaajaa, 4 taulukkoa ja 3 liitettä

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Avainsanat: Human-Machine-Interface, Industry 4.0, digitalisaatio, Requirements Engineering, Design Thinking, teknologian hyväksyntä

Industry 4.0 ja tuotantolinjojen digitalisaatio ovat kuumia aiheita lukuisilla teollisuusaloilla. Digitalisaation avulla pyritään saamaan kilpailuetua parantamalla tuottavuutta, nopeuttamalla läpimenoaikoja ja laskemalla hävikkiä. Jatkuvasti monimutkaistuvassa tuotantoympäristössä datalla on suuri rooli tuotantopäätöksissä ja valtava määrä dataa tuotetaan joka päivä, mikä tekee datan käsittelystä entistä vaikeampaa. Sopivia digitaalisia työkaluja on kehitettävä, jotta yritys pystyy pärjäämään yhä kilpailuhenkisemmässä toimintaympäristössä.

Tämä diplomityö hyödyntää Requirements Engineering ja Design Thinkingin yhdistelmää tavoitteenaan ymmärtää tuotantolinjojen johtajien tarpeita ja haasteita, joiden pohjalta luodaan alustava lista vaatimuksista seuraavan sukupolven ihmisen ja koneen välisille käyttöliittymille. Tämä diplomityö myös tutkii työntekijöiden asenteita potentiaalisia tuotantolinjojen johtajien työn tukemiseen integroitavia teknologioita kohtaan. Analyysin perusteella luodaan priorisoitu suosituslista tulevaisuuden käyttöliittymien kehitysprojekteista.

ACKNOWLEDGEMENTS

I would like to thank my supervisors Andrzej Kraslawski from Lappeenranta University of Technology and Christian Ruppel from Continental Automotive GmbH for your invaluable support and guidance in the process of writing this thesis. This would have not been possible otherwise.

A great thank you goes of course to my family for your endless love and support and level of patience in following my journey to the point where I am today. The love spans enormously long period of time, years longer than what writing this thesis has taken me. And of course big thumbs up to all of my friends who were there for me when I needed it the most.

I would like to also thank Continental Automotive GmbH for giving me this opportunity to put my skills to the test, apply the knowledge I have gained over the years to produce this master thesis and of course to develop my skills even further and to grow as a person. This was a long learning experience that I will not soon forget.

With the highest of spirits,

Lassi Uusitalo

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LIST OF ABBREVIATIONS

C-TAM-TPB	Combined TAM and TPB
DT	Design Thinking
HMI	Human-Machine-Interface
IDT	Innovation Diffusion Theory
JAD	Joint Application Development
KPI	Key Performance Indicator
MM	Motivational Model
MPCU	Model of PC Utilization
PDP	Physical-to-digital-to-physical loop
RE	Requirements Engineering
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
SCT	Social Cognitive Theory

1 INTRODUCTION

In this chapter a holistic explanation is given on the background of the thesis topic, why it was chosen and how the research is conducted. In the chapter "1.1. Research background" it is explained how the topic is narrowed down from the broad topic of Industry 4.0 to the specific problem in the Regensburg plant of Continental Automotive GmbH. In the chapter "1.2. Research problem and objectives" the research questions and research objectives are presented and the research scope and limitations of this master thesis are explained in chapter "1.3. Research scope and limitations". In the chapter "1.4. Research methodology" the research methods chosen for solving the research questions and reaching the research objectives are explained in detail. In the chapter "1.5. Research structure" the flow of the thesis is visualized via an input-output-chart and each chapter in this master thesis is explained briefly.

1.1. Research background

Due to the continuous increasing competition and advancements in technology over time, several manufacturing industries have had to revise their business models and manufacturing processes in order to gain competitive advantage in their markets through increased productivity, quality of the manufactured products and lowered manufacturing costs. According to Wahlster (2012) "manufacturing processes are increasingly complicated, automatic and sustainable, which means that machines are operated persistently, efficiently and in a simple manner". Since the first industrial revolution manufacturing industries have changed dramatically from water and steam powered engines to electrical and digital automated production. (Qin et al., 2016)

With the development of new state-of-the-art technologies such as Cyber-Physical Systems and Internet of Things in the last decade, the concept of the Fourth Industrial Revolution, more commonly known as Industry 4.0, was first introduced in Hannover Messe in 2011. Since the introduction of the concept, several European manufacturing research organizations and companies have produced work on this topic (Qin et al., 2016) According to Cotteleer & Sniderman (2017) Industry 4.0 is transforming the way companies are conducting their businesses from manufacturing their products to managing their supply chains and even collecting data from their customers in order to acquire insights on their current and future needs. The integration and visualization of data from multiple sources is increasing its importance in the daily operations of manufacturing companies. Figure 1 shows how the iterative cycle of physical-to-digital-to-physical (PDP) loop works. The PDP consists of three steps:

1. Physical to digital: Create a digital record from data from the physical world
2. Digital to digital: Use advanced artificial intelligence, scenario analysis and advanced analytics to uncover meaningful information and share information
3. Digital to physical: Translate digital-world decisions to effective data by applying algorithms to spur action and change in the physical world

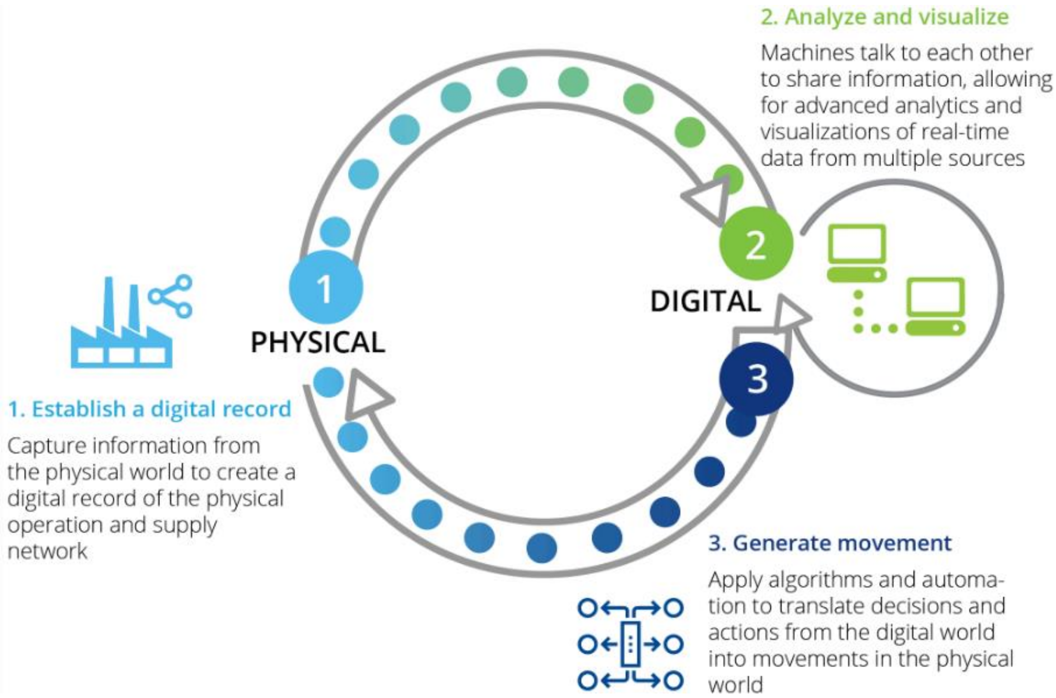

Figure 1. Physical-to-digital-to physical loop and related technologies (Cotteleer & Sniderman, 2017)

Today 91% of industrial companies in Germany are investing in digital factories and related technologies. Out of the 200 respondents of the study conducted by PricewaterhouseCoopers GmbH, 6% of the companies have already fully digitized their factories while 44% of companies say that some of their elements already connected in their factories, and 41% of companies say that they are using digital technologies for stand-alone solutions in their factories. Continental Automotive GmbH is in the forefront of developing a fully interconnected factory by initiating several Industry 4.0 initiatives, which aim to reduce failure rate, increase quality and reduce costs through data analytical methods. (Geissbauer et al., 2017)

A generalized concept of an assembly cell in a production line operating in Industry 4.0, which was developed in the Technical University of Vienna, is illustrated in Figure 2. In Continental Automotive GmbH several of these elements are already integrated in the production floors and as of today the production lines produce massive amounts of data on a daily basis. Although there is a vast amount of raw data available, there are only limited digital tools used to support the employees in various management functions which would allow them to easily access the insights of the acquired data in real time in order to make quicker and more accurate decisions.

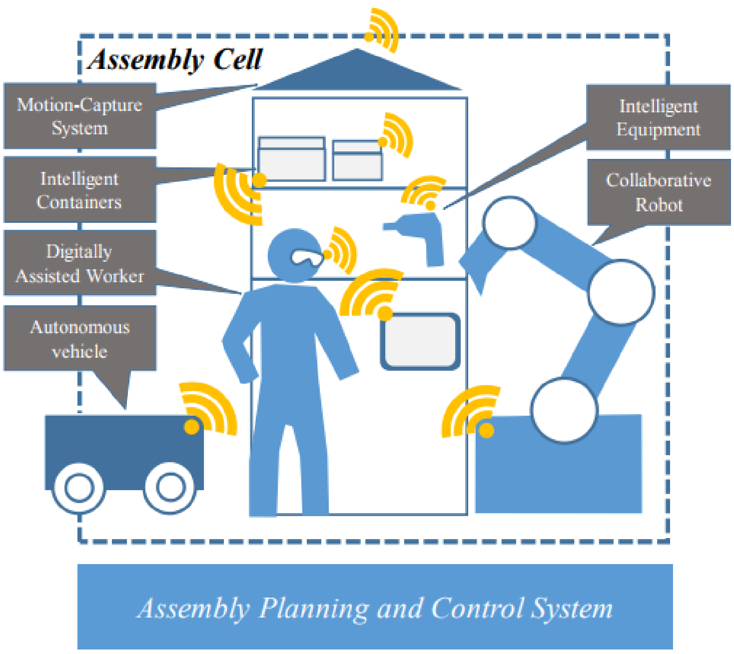

Figure 2. Assembly cell concept for the TU Wien Pilot Factory (Erol et al., 2016)

In order to introduce digital tools to support production floor workers in their work, there needs to be a human-based approach in the design process for the next generation of Human-Machine-Interfaces (HMI) to ensure that they are intuitive to use from the beginning. This means that in order to mitigate change resistance we must first understand what problems employees are facing with the existing tools and what could be done to design tools which would add value to the existing work in the future without changing the existing routines dramatically. Since there is an abundance of possible digital tools that could be introduced, we must also understand the level of social acceptance of each tool in order to prioritize future development projects of respective HMIs.

1.2. Research problem and objectives

The aim of this research is to gain a deep understanding of the way people in different levels of the organization in the production lines work, what are their explicit and underlying needs, and based on those needs formulate an initial list of stakeholder requirements for the next generation of HMIs for portable and wearable devices, which can be used as a basis for future development process. This research also investigates the effort expectancy and performance expectancy related to existing smart devices that could potentially be integrated in the production floor workflow by measuring employees' experience in using the devices and their attitudes towards them. This research aims to specifically answer the following questions and fulfill the related objectives:

Research question 1: What challenges and needs do different production line managers have with digital tools in Continental Regensburg plant?

Research question 2: Which portable and wearable devices can be introduced into the production floor workflow in Continental Regensburg plant with the least amount of change resistance and effort required from workers to learn to use the device?

Research question 3: How to ensure a successful design and implementation of new digital systems in the production lines?

Objective 1: Based on the identified user needs, propose an initial list of stakeholder requirements for future digital tools, which can be used as a basis for future development projects.

Objective 2: Based on the identified user needs and technology acceptance analysis, propose a prioritized list of development projects and propose next steps for the development and implementation of the respective HMIs for each digital tool.

1.3. Research scope and limitations

The scope of the research will be on the people working directly on the production floor and the supporting industrial engineers in two focus factories in the production plant in Regensburg. The main focus is on shift leaders, line leaders, technicians and industrial engineers who are most likely to adopt the new HMIs once they are introduced into the workflow. Machine operators will also be involved in the evaluation of the level of technology acceptance on the production floor.

Not part of the scope are parallel departments such as logistics, human resources or other production floors not already included in the study. This research paper will also not investigate physical infrastructure requirements for integrating portable devices in the workflow on the production floor, cloud requirements for data gathering and distribution from machine to other devices or the maturity level of the technologies that are involved in the study in order to keep a clear focus on the human factors of the design and change management process. In Requirements Engineering process this research is limited to requirements elicitation and will leave requirements analysis and consequent phases to the HMI development team in Continental Regensburg. In Design Thinking this thesis covers the Research phase and early part of Ideation.

The limitation of the empirical quantitative study is that the survey is conducted on a voluntary basis, meaning that people who participated in the survey were already willing to engage in the topic which means that produced data is representative of only a part of the production floor work force and not the whole population within the limits of this study. Therefore the data serves as indication of the overall situation and making absolute conclusions from the data should be avoided.

German privacy laws mandate that all surveys must be made completely anonymously and from the data you should not be able to identify groups which are smaller than five people in order to ensure that no one can identify which individual person has sent which answers to a survey based on an analysis of a combination of variables. The Works Council (Betreibsrat) also prohibited me from conducting gender based analysis when conducting a survey on technology acceptance and attitudes on the shop floor based on concerns that the results could be discriminatory on the basis of the Equality Act. This is why this variable has been removed from my analysis even though it plays a central part in the technology acceptance model which is explained in chapter “3.1. Unified Theory of Acceptance and Use of Technology”.

1.4. Research methodology

In this research literature, quantitative data, and qualitative data will be used to analyze the existing attitudes towards existing methods and potential technology applications. Proposals for the future steps of the HMI development process and the introduction of the finished HMIs into the workflow on the production floors will be formed. Table 1 summarizes what research methods are used to gather information for the exploration of the respective research questions and what are the outputs of each method which are used as input for further analysis.

A literature review is conducted in order to benchmark existing studies and to gain theoretical background knowledge on requirements elicitation and technology acceptance, which are used to create frameworks for the empirical research. The empirical research is done in two parts. First there is the qualitative survey aimed at the managers in different levels of the production line hierarchy conducted in German and analyzed in English (Appendix 1). The aim is to use the qualitative data to form customer profiles of each role in the management, do stakeholder analysis, and to elicit underlying and explicit needs and requirements for the HMI design. Second there is a quantitative survey on the production floor which is conducted in German and analyzed in English (Appendix 2). The aim is to provide quantitative data on people’s familiarity and attitudes towards portable and wearable smart devices. Recommendations on prioritizing future HMI projects are made based on the outcomes of a demographic analysis of the acquired data of the quantitative survey.

Table 1. Research questions, tools and outputs of the tools

Research question	Research methods	Outputs of the research methods
Research question 1: What challenges and needs do different production line managers have with digital tools in Continental Regensburg plant?	Literature review	Theoretical framework for needs and requirements elicitation
		Identification of recommended design principles for HMIs
	Management survey	Qualitative data of the stakeholders’ work responsibilities
		Qualitative data of the stakeholders’ working methods
		Qualitative data of the stakeholders’ interactions with their counterparts
Research question 2: Which portable and wearable devices can be introduced into the production floor workflow in Continental Regensburg plant with the least amount of change resistance and effort required from workers to learn to use the device?	Literature review	Identification of factors that affect technology acceptance
	Production floor survey	Quantitative data of the employees’ familiarity with smart devices
		Quantitative data of the employees’ attitudes towards smart devices
		Quantitative data on the employees’ perceptions on their co-workers’ attitudes towards smart devices
Research question 3: How to ensure a successful design and implementation of new digital systems in the production lines?	Literature review	Identification of recommended design principles for HMIs
		Identification of psychological factors in technology-driven change
	Production floor survey	Analysis on the effect of people’s experience in use of technology towards their attitude to its implementation

In the end the literature review is combined with the empirical findings of the qualitative management survey and quantitative production floor survey. The analysis of the findings will form a basis for the final conclusions and recommendations. Table 2 summarizes what final inputs are used to reach the conclusions in order to reach the research objectives and to answer the research questions.

Table 2. Research objectives, inputs and final outputs

Research objective	Input	Final output
Objective 1: Based on the identified user needs, propose an initial list of stakeholder requirements for future digital tools, which can be used as a basis for future development projects.	Stakeholder needs analysis	Initial list of stakeholder requirements for future HMIs
Objective 2: Based on the identified user needs and technology acceptance analysis, propose a prioritized list of development projects and propose next steps for the development and implementation of the respective HMIs for each digital tool.	Quantitative analysis on familiarity and attitudes towards technology	Prioritized list of development projects
	Literature review	

1.5. Research structure

In order to gain a coherent understanding of the flow of the thesis it is important to visualize the structure of it the pathway from research questions to the final conclusions. This is demonstrated in Figure 3 on the next page.

In chapter “1 Introduction” the background of this master thesis has been explained and narrowed down to a specific problem out of which the research questions, research objectives and research scope and limitations have been defined. In chapter “2 Human-Machine-Interface design process” we explore literature related to requirements engineering, Design Thinking and HMI design principles in order to gain understanding on how the design process of the future HMIs beyond the scope of this master thesis should work. The theoretical frameworks of this chapter are used as a basis for the design of the management survey and recommendations for the future steps of the interface development.

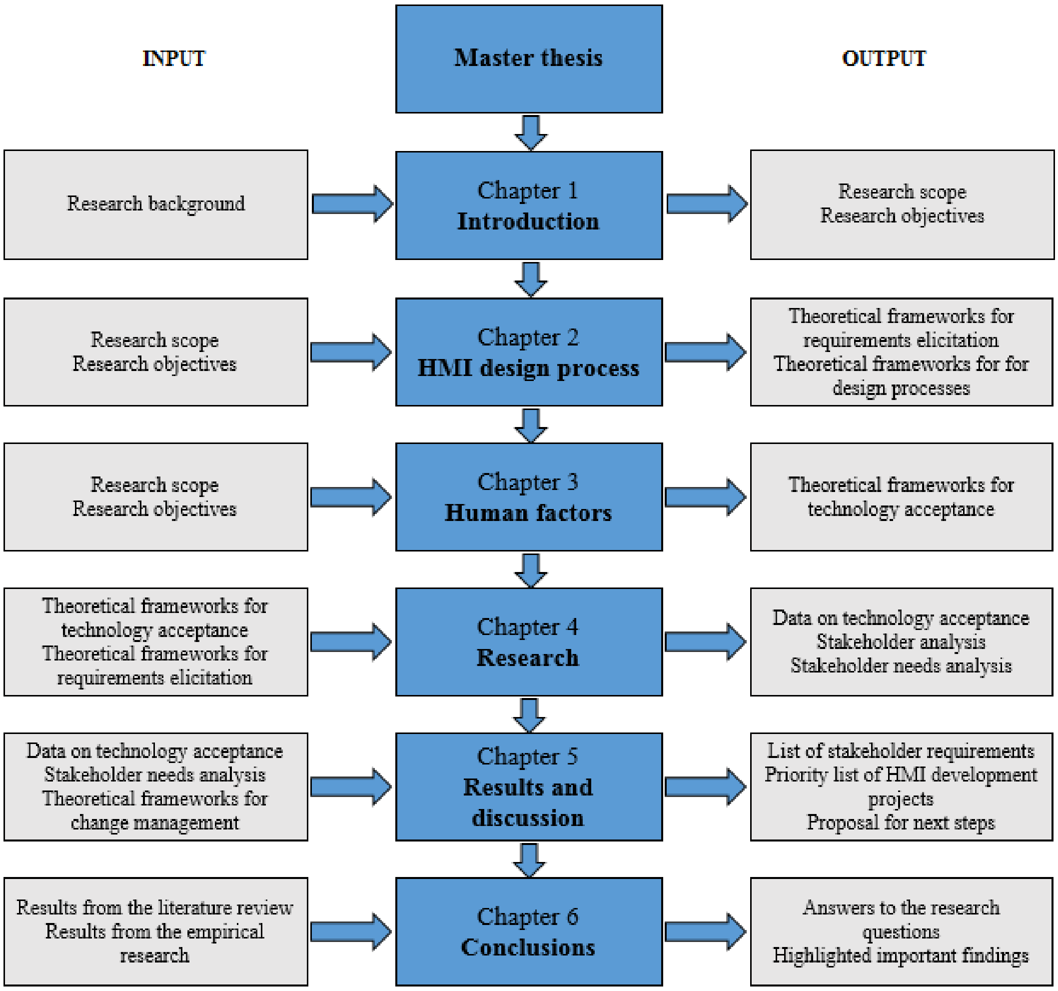

Figure 3. The structure of the master thesis

In chapter "3 Human factors" we explore literature related to human psychology when it comes to technology acceptance and what strategies are there for pushing technology-driven change in a company. From the literature we elicit theoretical frameworks for technology acceptance which are used as a basis for the production floor survey. In chapter "4 Research" the theoretical frameworks are put into use and the results of the surveys are analyzed. Based on the results of the analysis stakeholder profiles are made and stakeholder needs are identified. Demographic analysis on technology acceptance is made to form a basis for HMI project prioritization recommendations.

In chapter “5 Results and discussion” the results of the surveys are discussed, user requirements are identified and a priority list for future development projects is created. Some of the most interesting findings will also be highlighted. Finally in chapter “6 Conclusions” all of the most important findings from literature and empirical research are highlighted and the research questions are answered based on what has been found in researching the topic.

2 HUMAN-MACHINE-INTERFACE DESIGN PROCESS

This chapter explains the theoretical frameworks of design process thinking that are used as the approach for this investigation. In chapter “2.1. System development process” the long-term process of starting from an idea of a new system to realizing it is explained from stakeholder needs to designing subsystems of the developed system. In chapter “2.2. Requirements Engineering” the traditional Requirements Engineering method is explained in detail from requirements elicitation to requirements management. In chapter “2.3. Design Thinking” the agile creativity process is explained and what value it can add to traditional Requirements Engineering. Finally chapter “2.4. Design principles” will give an overview of characteristics of a well-designed HMI and other ergonomic principles that should be kept in mind while designing a new HMI.

2.1. System development process

Before you can start developing any new system, it is critical that you establish a need for the system being developed. If is not known what the purpose of the system will be, it is not clear what sort of system will be developed and when it is developed there is no guarantee that it will meet the user needs. The detail in which a need in a specific role in an organization depends on the person expressing the need. The need might be expressed vaguely, eg. “I would like to have a system that makes my work faster.” Obviously such a vague “specification” cannot be used as a good basis for developing a new system or buying one from an external party. However, it can be used as basis for studying what the person really wants. Such a study would need to determine what is making a person’s work time-consuming or what other inefficiencies are creating obstacles in one’s work. In order to transform vague statements into a set of actionable requirements, you need to follow a series of activities that are part of the process of developing stakeholder requirements. Stakeholders include people who interact with the system directly but also other people who have an invested interest in the system. (Dick et al. 2017)

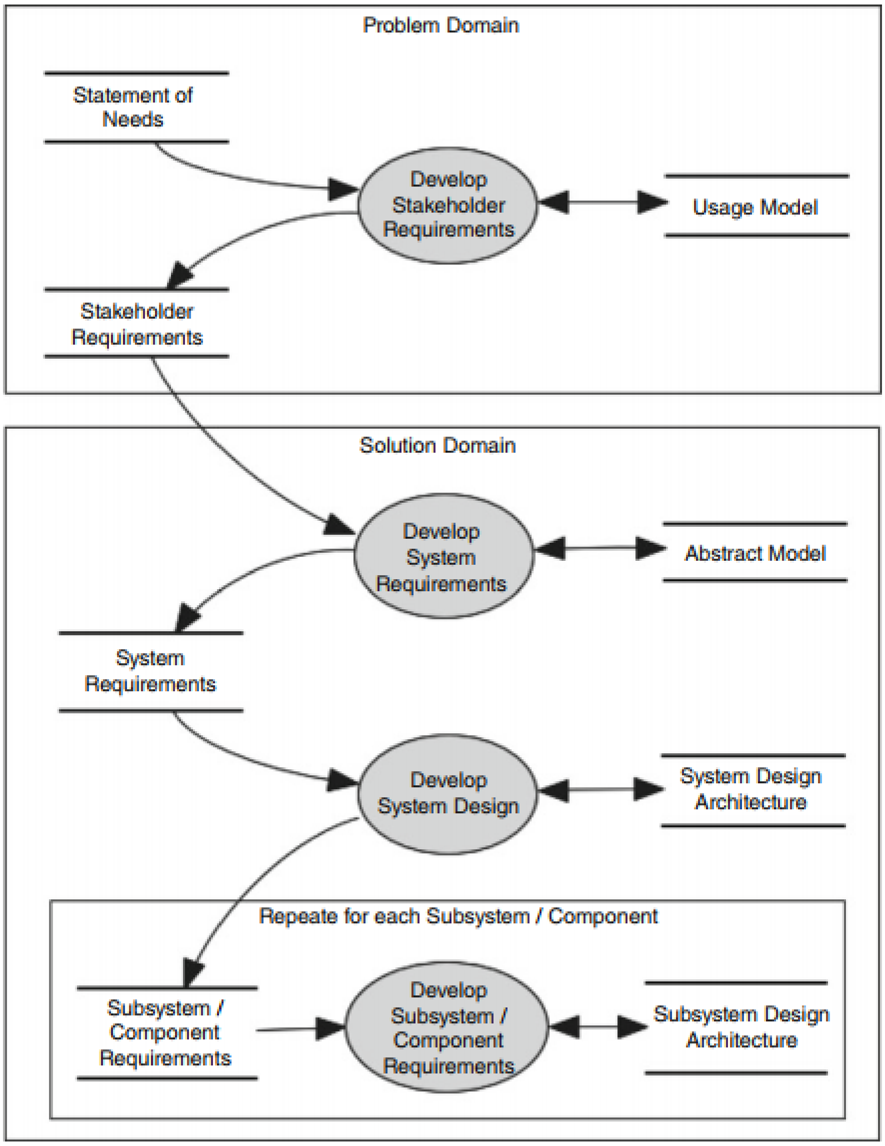

Figure 4. System development process (Dick et al. 2017)

Figure 4 illustrates the development process in the form of a data flow diagram where ovals represent processes and rectangles represent data or information that is being read or produced. The arrows represent the direction of the information. For example, the “Develop stakeholder requirements” takes the “Statement of needs” and produces ”Stakeholder requirements”. It also creates and reads a “Usage model”. Once an agreed upon set of stakeholder requirements are produced, which define what users want to be capable of doing with the future system, we can start thinking about potential solutions. Instead of starting with the design right away, it is good practice to first determine what characteristics the system should have regardless of what the final design will be. This is the process of establishing system requirements. To support a common understanding of the system being developed within the development team, it is recommend to create an abstract architectural model of the proposed system. This provides a basis for discussing the potential solution with a similar understanding about the system being developed. The abstract model can also be used for communicating with stakeholders about the progress of the development project and it serves as a structured way of presenting and documenting system requirements. (Dick et al. 2017)

From system requirements it is possible to develop system design requirements and system design architectures. Design architecture expresses how different components of a system interact with each other in order to collectively exhibit desired properties that should match the desired characteristics of the system as defined in system requirements. The design architecture expresses how each component must work and how to produce desired overall effects by interacting with other components and defines the requirements for each system component in terms of their functionality and interaction obligations. The design architecture and the system component requirements must also determine other required properties such physical size, reliability, maintainability etc. (Dick et al. 2017)

With the exception of the smallest systems, most of the components in the design architecture would be too complex to be implemented right away. Components at this level are often referred to as “subsystems” because they are complex enough to be systems of their own but they are part of the higher-level system that they are being designed for. Establishing subsystem design architecture and then developing component requirements for them works in a similar way as establishing design architecture and developing component requirements for the overall system. (Dick et al. 2017)

In this master thesis the focus will be on problem domain part of the process where a list of needs is developed and processed into stakeholder requirements. Some suggestions may be given for solutions but overall, developing system requirements will be the responsibility of the respective expert in the development team.

2.2. Requirements engineering

Requirements engineering (RE) can be described as a systematic process of identifying, modeling, communicating and documenting the requirements for a system that is being developed in the contexts where the system will be used. Traditional RE consists of five phases: requirements elicitation, requirements analysis, requirements documentation, requirements validation and requirements management. (Paetsch et al. 2003) Besides writing requirements, RE focuses on understanding the real underlying problem and discovering and understanding the client needs. (Robertson & Robertson 2013) RE relies on consulting relevant stakeholders which is why it is important to identify them before starting with the development process. Figure 5 summarizes the overall RE process.

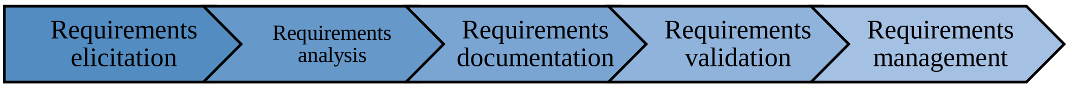

Figure 5. Requirements engineering process overview

2.2.1. Requirements elicitation

The aim of the first step of RE, requirements elicitation, is to discover requirements and to identify system boundaries by consulting clients, users, developers and other stakeholders. In order to understand the system that is to be developed, it is essential to first understand the business needs, application domain, stakeholders, system constraints and the problem itself. The most important techniques for requirements elicitation are described below. (Paetsch et al. 2003)

Interviews: Interviewing is a method used for discovering facts and opinions of potential users of the system being developed. The interview can be done in a closed interview, in which the requirements engineer has a fixed set of questions to which he is looking for answers or an open interview where he/she is looking for answers, or in an open interview without pre-defined questions where the requirements engineer and the stakeholders discuss in an open-ended way what is expected from the system. The advantage of interviews is the potentially rich collection of information that the developer gets from them. The disadvantage is that analyzing the large amount of qualitative data can be very difficult and there could be potential conflicting information given by different stakeholders. (Paetsch et al. 2003)

Use cases / Scenarios: Use cases describe how the system and the users interact and focus on what users need to do with the system. Use cases can be used in the early stages of the development process and represent the software system's functional requirements. Every proposed use case should be inspected by customers and analysts in order to validate it. Scenarios are simulations of a single type of interaction between a system and the user to demonstrate examples of interaction sessions. Scenarios should describe the state of the system before and after the scenario, what simultaneous activities there might be, what is the normal flow of the events, and what are the exceptions to the events. (Kotonya & Sommerville, 1997)

Observation and social analysis: In observational methods investigators view as they are working and take notes on the activities that occur. Observation can happen either directly where investigators are present during the task or indirectly by viewing the tasks by other ways, for example via video records. Observation enable the observer to see what users are doing in reality in the context which helps with overcoming issues with stakeholders giving descriptions of work processes that are idealized or more simple than in reality. (Paetsch et al. 2003)

Focus groups: Focus group is an informal technique that is used to help understand user needs and perceptions, what things are important to users and what they want from the system. Focus groups are facilitated by gathering groups of four to nine people with different backgrounds and different skills to discuss issues and concerns about features of a system prototype in a free form setting. Focus groups can support the articulation of product concepts, visions and design proposals and they often bring out spontaneous reactions and ideas. (Paetsch et al. 2003) They also help in developing a "shared feeling" of the system among users and to analyze what things should be changed. (Macaulay, 1996) Since what people say and what people do can be very different from each other, it is a good idea to complement focus groups with observational analysis. (Paetsch et al. 2003)

Brainstorming: Brainstorming is a technique used for developing creative solutions for specific problems. It consists of two phases: first ideas are collected in the generation phase and then the ideas are discussed in the evaluation phase. Ideas should not be criticized or evaluated in the generation phase as the aim is to develop a broad set of different ideas in a short period of time. Brainstorming helps in understanding the problem better and a feeling of common ownership of the result. (Paetsch et al. 2003)

Prototyping: A prototype is an early version of a system that is available in an early phase of the development process. Prototypes of software systems are often used to assist in elicitation and validation of system requirements. Prototypes can be either throw-away prototypes, which are used to help understanding difficult requirements, or evolutionary prototypes, which are used to provide a customer with a workable system which often may be integrated in the final system. Prototypes can be paper based mock-ups of the system being developed, input-response type of simulations, or automated prototypes where executable prototypes are developed in a rapid development environment. (Paetsch et al. 2003)

2.2.2. Requirements analysis

Requirements analysis checks for:

- Necessity: is there a need for the requirement,
- Consistency: the requirements should not contradict one another,
- Completeness: no missing services or constraints, and
- Feasibility: how feasible the requirements are in the context of the available budget and schedule for the system development.

Conflicting and disputed requirements need to be prioritized by negotiating with the stakeholders in order to identify critical requirements. In requirements analysis three most used techniques are Joint Applications Development (JAD) sessions, Prioritization and Modeling, which are used to identify solutions to requirements problems and to agree upon a compromise set of requirements with the stakeholders. (Paetsch et al. 2003)

JAD is a facilitated workshop with a structured analysis approach where developers and customers discuss desired product features. The role of the facilitator is to make sure that people stay on topic to ensure a productive discussion. The aim of JAD is to define a special project on different levels, to design a solution, and to monitor the project until it is finished. Participants may consist of executives, project managers, users, system experts and external technical personnel depending on the nature of the project. (Macaulay 1996) JAD promotes diversity of backgrounds of participants of the workshop and cooperation, understanding and teamwork between the different participant groups which should help with gathering information regarding various parts of the new system to provide a base for further requirements elicitation. (Paetsch et al. 2003)

When you have a project with limited resources, tight schedule and high customer expectations, it is important to prioritize requirements early in the project with the intention to decide which features to leave out under time pressure, in order to deliver the most valuable features as soon as possible. Requirements prioritization is a discussion between the customers and the developers where customers outline or rank features which provide the greatest benefit and have the highest priority to them, and the developer point out technical difficulties or costs related to the feature. Based on the input and information from both sides the customers might change the prioritization of some features and developers might propose features which were not prioritized so high earlier but have a higher impact on the system's architecture. The overall prioritization of requirements should be decided by the customers (or end users) of the system being developed. (Paetsch et al. 2003)

System models are used as bridge between the analysis and the design process. System requirements are described using various methods which use different modeling techniques, the most popular ones being data-flow models, semantic data models and object-oriented approaches (Kotonya & Sommerville 1997)

2.2.3. Requirements documentation

Requirements documentation is used to communicate the requirements between stakeholders and developers and is used as a basis for evaluating the subsequent products and processes and for change control. A good requirements document is feasible and consistent, easy to understand, contains correct information, and is unambiguous. (Paetsch et al. 2003)

There is a necessity to carefully balance between two aspects when writing a requirements document: the need to ensure the readability of the requirements document and the need to make a processable set of requirements. If the developed system is highly complex, the requirements documentation can become very large as you get into more detail. It is essential to have well-understood and clearly documented structure for the set of requirements in order to manage the complexity of the system effectively. It may be helpful to organize the set of requirements in the right structure by keeping the number of requirements to minimum, detecting omissions and duplications and eliminating conflicts between requirements. Your aim should be finding sets of requirements related to particular topics, understanding large amounts of information and manage iteration for example in delayed requirements. All requirements should be evaluated to reject poor requirements and whenever possible, reuse requirements in different projects. (Dick et al. 2017)

Requirements documents are typically hierarchical and contain sections and subsections in multiple levels. In addition to requirements statements the requirements documents may include technical and non-technical text in order to give context to the requirements and make it easier to understand them. These may include for example contextual background information, defined scope of the requirements, external context that describes the system, stakeholder descriptions, and definitions of terms that are used in the requirements statements. In addition there may be descriptive texts that bridge different parts of the documents, a summarized list of models that are used to derive the requirements and references to other documents. (Dick et al. 2017)

It is important to use consistent language in the requirements documentation in order to make it easier to identify different types of requirements. Examples of this are the key words “must” or “shall” which are used to make the presence of a requirement more apparent in a text. It is also possible to use "should" and "may" to indicate different levels of prioritization of a requirement. In addition to the language aspects the requirements statements should follow certain criteria, namely each statement should be uniquely identifiable, clear to understand, precise and verifiable. Each statement should carry a single traceable element, be technically and legally possible to realize within the given costs and schedule and the statement should not impose any particular design solution to the layer below it. (Dick et al. 2017)

Besides requirements for individual requirements statements there are separate requirements a set of requirements as a whole should follow. Sets of requirements should be complete, consistent and non-redundant. In addition requirements that are connected should be close to each other, the structure of the requirements document should be clear and an appropriate degree of traceability of the requirements should be achieved. Here an example of an actual"nightmare" requirement is provided: (Dick et al. 2017)

"The system shall perform at the maximum rating at all times except that in emergencies it shall be capable of providing up to 125% rating unless the emergency condition continues for more than 15 minutes in which case the rating shall be reduced to 105% but in the event that only 95% can be achieved then the system shall activate a reduced rating exception and shall maintain the rating within 10% of the stated values for a minimum of 30 minutes."

An analysis of this example shows that there could be 12 requirements included in this statement. A better approach would be to make a clear distinction between different modes of operation, for example normal, emergency, emergency more than 15 minutes, and for each mode express a separate requirement. In general, Dick et al. (2017) advice avoiding the following common "pitfalls" in requirements documentation:

- *Avoid rambling*: conciseness is a virtue, a requirement statement should not be a novel

- *Avoid let-out clauses* such as “should it be necessary” which render the requirements useless or non-applicable
- *Avoid putting more than on requirement in a paragraph*, often indicated by the word “and”
- *Avoid speculation*
- *Avoid vague words*: usually, generally, often, normally, typically
- *Avoid vague terms*: user friendly, versatile, flexible
- *Avoid wishful thinking*: 100% reliability, please all users, safe, run on all platforms, never fail, handle all unexpected failures

2.2.4. Requirements validation

The purpose of requirements validation is to confirm that the developed requirements are an acceptable description of the system that is to be implemented. The inputs for the requirements validation procedure are requirements document, organizational knowledge and organizational standards. The outputs are a list of reported problems with the requirements document and the actions that are deemed necessary to cope with the reported problems. Requirements validation techniques include requirements review and requirements testing. Usually requirements validation leads to sign-offs from all project stakeholders. (Paetsch et al. 2003)

2.2.5. Requirements management

Requirements management aims to capture, store, disseminate and manage information. Requirements management involves activities related to requirements tracing, requirements tracking, and change and management control. In order to manage changes to a system, requirements traceability provides relationships between requirements, design, and implementation of a system. (Paetsch et al. 2003)

2.3. Design Thinking

Design Thinking (DT) is a human-based creativity technique which aims to understand the perspective of the users and to understand the system as whole in its full context. Requirements management has turned into an increasingly difficult task through the increased complexity of embedded systems. Additionally there is a demand for innovative systems which may be developed by adopting DT alongside of the traditional RE. DT can minimize the amount of problems throughout the development cycle of new systems, improve the requirement elicitation process and increase the quality of the final system through innovative solutions. The DT process consists of 4 phases: Research, Ideate, Prototype and Testing. These phases might not be necessarily in that order and might even happen simultaneously. The general idea of DT process is illustrated in Figure 6. (Araújo et al. 2015)

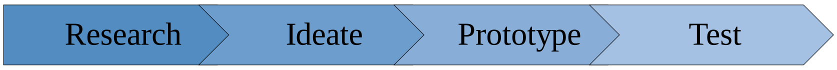

Figure 6. Design Thinking process (Araújo et al. 2015)

Research: The main objective of the research phase is to understand the context in which a developed solution is going to exist and what kind of interactions the solution will have with other things in the given environment. You also need to empathize with the user of the solution meaning that you need to have their perspective in order to understand their real needs in order to create an efficient solution that solves the real problem. Even though traditional requirements elicitation also addresses the users' real needs, its focus is on the software aspect of a system, whereas DT sees the system as a whole in its full context without ignoring any part of it. This means that throughout the development not only is the product itself considered, but special attention is also given to the overall context and user environment where the product is used. (Araújo et al. 2015)

Ideate: Once there is an understanding of the context and user real needs, you can start creating possible solutions to a particular problem that the system is supposed to solve. In the ideation phase you collect together the perspectives of all stakeholders without setting any restrictions to the generated ideas. The aim is to be creative and use your imagination. Nevertheless in DT collaboration is the key in ideation phase where it is better to have a group of people working on one idea for one day instead of one person working on one idea for several days. This way you can increase perspective variety and avoid a higher amount of thought intersections. At the end of Ideation phase, a single solution is selected for refinement. Therefore although Ideation requires many ideas and creativity, critical thinking is also needed in order to evaluate the viability of the final solution. Compared to traditional idea creation techniques such as brainstorming for solving a defined problem, Ideation process is more visionary and can be used to discover solutions for problems that have not yet been defined. Ideation allows to see the same situation from many angles which could lead to rethinking and redesigning the problem which further allows the generation of several different approaches to achieve the same end result. (Araújo et al. 2015)

Prototype: In Prototype phase of DT, ideas generated in Ideation phase are experimented and developed. While in traditional RE prototyping is used to get feedback from customers and end users to understand if the solution that is under development is satisfying their needs, DT goes beyond that by explicitly embracing the concept of early failure. In essence the aim is to fail as early as possible, learn from mistakes and start again with a new prototype. This way a quality product can be created in a shorter time period. This also allows experimenting with different and innovative ideas in a safe environment until a prototype succeeds. Rapid prototyping also serves as a form of analysis of the solution because you can observe for example which ideas work, which ideas need further refinement or do not work at all, which solutions are too complicated or simple and so on. (Araújo et al. 2015)

Testing: Last part of the DT process is testing. This is when the solution is tested in the real operating environment with the minimum viable product to verify its performance through metrics and to gain feedback. Testing is a constant part of DT and should be done every time a new prototype is created. This creates a cyclical nature to testing since during product development process a lot of prototypes are created. DT process is a very iterative in nature in general as you go through the cycle of early failure, learning from the mistakes and rebuilding several times until the desired product is according to the specified requirements.

There are several ways of designing a product to be the most convenient for the customer or end user. In order to be successful in such an effort you have to look at the proposed product from the perspective of the person who will use it in the end. When developing a product it is not important what the development thinks it should do, but rather you have to approach the developed product from the customer's or end user's point of view. Sometimes, due to the number of end users, it is not possible to gather input from everyone through personal interviews in order to gain a full understanding of the customer needs. For this purpose it can useful to use personas to approach the thinking of the potential end user of a product. A persona is an imaginary, yet archetypical, representation of a customer or customer group whose attributes you can use to develop requirements. A persona is not completely made up, but rather derived from market research or other surveys into your likely user population. The degree of precision of a persona depends on the size of the population it represents and the criticality of the product being developed. Typically a development team creates a one or two page document which identifies and describes the persona's behavior patterns, goals, skills and environment which is used to try to understand the way of thinking of the respective persona and what the persona wants and needs. (Robertson & Roberson 2013)

2.4. Design principles

Over time the developments in computer and automation technology have lead towards increased automation in process control, allocating more and more functions to the computer since it is expected to be more reliable and less susceptible to errors or failures than humans are especially in routine tasks. While computers might be less prone to errors than humans are, they also possess less capability to find generic solutions for unexpected errors which have not been prepared for with programing. Therefore some tasks will still be left for people who operate process controls. Operators and managers must be provided with tasks for which they are suited and which will not overload in any way. This is not a process control design problem in particular, but a quite common problem in systems engineering in general. To tackle this problem certain general characteristics of well-designed tasks have been specified in European Standard EN 614-2. Since using a HMI can be considered to be a dialogue between the HMI user and the HMI itself, the design of the HMI should conform to certain ergonomic principles. An example of specified ergonomics is ISO 9241-10 which was developed for office systems but also apply in the design of process control systems. Table 3 presents a summary of the two standards. (Nachreiner et al. 2006)

Table 3. Summary of HMI design principles

Characteristics of well-designed tasks (EN 614-2)	Ergonomic requirements for office work with visual display terminals (EN ISO 9241-10)
• Take operator experience, capabilities and skills into account • Provide for task variety • Provide for task identity • Provide for feedback • Provide for autonomy • Provide for task completeness (hierarchical/sequential) • Provide for opportunities for the development of competencies • Avoid overload/underload • Avoid repetitive tasks • Avoid social isolation	• Suitability for the task • Self-descriptiveness • Controllability • Conformity with the user expectations • Error tolerance • Suitability for individualization • Suitability for learning

3 HUMAN FACTORS

When you are intending to introduce a new system of work, you need to consider the emotions of the end users in order to deflect change resistance and to ensure smooth adoption. The chapter "3.1. Unified Theory of Acceptance and Use of Technology" explains the ultimate theory of technology acceptance and how different factors affect behavioral intention. Chapter "3.2. Technology and emotions" explains how people approach new technology depending on their personal attitudes and goals. Finally chapter "3.3. Innovation diffusion theory" explains how and at what rate different groups of people adopt innovations and new ideas.

3.1. Unified Theory of Acceptance and Use of Technology

Information systems research has studied for a very long time *how* and *why* individual people adopt certain technologies. There have been several studies and theories on this and Ventakesh et al. (2003) did a cross-analysis on major behavioral models and theories to create Unified Theory of Acceptance and Use of Technology. They studied Theory of Reasoned Action (TRA), Technology Acceptance Model (TAM), Motivational Model (MM), Theory of Planned Behaviour (TPB), Combined TAM and TPB (C-TAM-TPB), Model of PC Utilization (MPCU), Innovation Diffusion Theory (IDT) and Social Cognitive Theory (SCT) in order to gain an understanding on common themes between the existing theories and models. They based their research on the basic concept underlying user acceptance models, demonstrated in Figure 4.

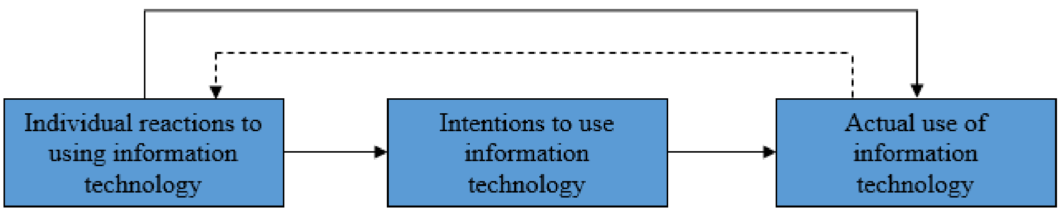

Figure 4. Basic concept underlying user acceptance models

Basically what is postulated is that there is a difference between the intention of use of technology and the actual use of technology which derives from the reactions of people have towards the use technology. Ventakesh et al. (2003) identified gender, age, experience and voluntariness of use to be the key moderators of technology acceptance of individuals. They also theorize that constructs of *performance expectancy*, *effort expectancy*, *social influence* and *facilitating conditions* play a significant role as direct determinants of user acceptance and usage behavior (Figure 5).

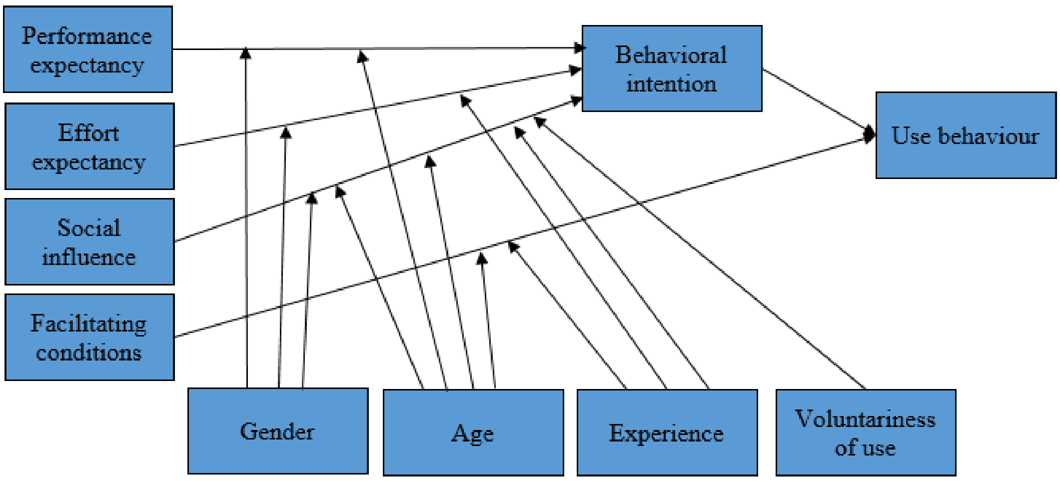

Figure 5. Research model on Unified Theory of Acceptance and Use of Technology (adapted from Ventakesh et al. 2003)

Performance expectancy is defined as “the degree to which an individual believes that using the system will help him or her to attain gains in job performance”. Based on the cross-analysis on existing models on technology acceptance Ventakesh et al. (2003) broke performance expectancy down to sub-constructs of perceived usefulness (TAM/TAM2 and C-TAM-TPB), extrinsic motivation (MM), job-fit (MPCU), relative advantage (IDT) and outcome expectations (SCT). These can be understood as the degree to which a person believes that using a system would enhance one’s job performance, how instrumental an active is believed to be to achieve desired outcomes that are distinct from the activity itself (for example improved job performance, pay increases or promotions), how the capabilities of a system enhance job performance, the degree to which an innovation is believed to be better to its precursor and what are the expected outcomes of a behavior. From the theoretical point of view Ventakesh et al (2003) expecte that *gender* and *age* are the main moderators of the relationship between effort expectancy and behavioral intention, such that the effect will be stronger for men and particularly for younger men. This is theorized on the basis of men being highly task-oriented and younger workers placing more importance on extrinsic rewards. Performance expectancy is said to be the strongest predictor of behavioral intention. (Ventakesh et al. 2003)

Effort expectancy is defined as "the degree of ease associated with the use of the system". This has been broken down to perceived ease of use (TAM/TAM2), complexity (MPCU) and ease of use (IDT). All these sub-constructs are similar to each other and in essence describe how understandable the system is to a person and how easy the system would be to use or how easy it would be to learn to use the system. Ventakesh et al. (2003) note that each sub-construct has a significant effect on the behavioral intention only in the early phases of technology introduction, becoming nonsignificant over extended and sustained period of use of a system. Effort-oriented constructs are more noticeable in the early stages of a new behavior when initial process issues cause challenges that need to be overcome by users, which later are surpassed by instrumentality concerns. Ventakesh et al. (2003) suggest that the influence of effort expectancy on behavioral intention is moderated by *gender*, *age* and *experience*. The effect is said to be more visible for women, and in particular for older women with little experience with a system. This is said to be because increased age is associated with difficulty in processing complex stimuli and allocating attention to information on the job and prior research suggests that the effect is stronger for women and older workers. (Ventakesh et al. 2003)

Social influence is defined as "the degree to which an individual perceives that important others believe he or she should use the new system". This is broken down to subjective norm (TRA, TAM2, TPB/DTPB and C-TAM-TPB), social factors (MPCU) and image (IDT). In essence each sub-construct has the explicit and implicit idea that the individual's behavior is influenced by the way in which they believe others will view them as a result of having used the technology. The compliance mechanism alters an individual's intention in response to social pressure or how the individual responds and intends to comply with the social influence, while the latter two relate to causing an individual to respond to potential status gains and/or even alter an individual's belief structure. (Ventakesh et al. 2003)

Research on technology acceptance by Hartwick & Barki (1994) indicates that relying on other people's opinions is significant only in *mandatory* settings, especially in early stages of experience when a person's opinions are based on inadequate facts and perceptions. Normative pressure decreases over time with increased *experience* which leads to the significance of social basis for individual intention to use the system to decrease in favor of a more instrumental basis. (Ventakesh et al. 2003)

It is suggested that gender, age, voluntariness of use and experience moderate the influence of social influence to behavioral intention to such degree that the effect is stronger for older women in early stages of experience in mandatory settings. Theory suggests that social influence is more salient to *women* when forming an intention to use new technology as they tend to be more sensitive to the opinions of other people. This effect declines with increased experience with using a system. (Ventakesh et al. 2003)

Facilitating conditions are defined as "the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system". Three different constructs embody concepts captured by this definition: perceived behavioral control (TPB/DTPB, C-TAM-TPB), facilitating condition (MPCU), and compatibility (IDT). (Ventakesh et al. 2003) How this could be understood is that to what degree a person believes a system fits to one's work, to what degree there is support available in case of system problems and how compatible the system is to other systems that are already in use. The empirical research of Ventakesh et al. (2003) suggests that the relationships between each construct and intention are similar to each other and that they have an impact in both voluntary and mandatory settings immediately after initial training but the influence constructs have on intention fades over time. Facilitating conditions overlap with effort expectancy, which captures the ease of use of a system. In other words, as you are more experienced with using a system, the need for support structures and instructions becomes less significant over time. It is suggested that if performance expectancy and effort expectancy are present, or in other words if a system is found to be useful for one's work and/or it is easy to use, then facilitating conditions as a predictor of intention becomes non-significant. It is suggested that the effect of facilitating conditions is stronger with increased age and experience as over time you find several ways of finding required information and also because older workers find the importance of receiving assistance and help in one's work to be higher. (Ventakesh et al. 2003)

3.2. Technology and emotions

According to Stam and Stanton (2010) technology diffusion, adoption, and acceptance each refer to "overlapping aspects of the human dynamics by which new artifacts become (or fail to become) embedded in the social and business processes of organizations". They explored Regulatory Focus Theory and Affective Events Theory in order to create an emotion-focused model for adaptation of technology.

Regulatory Focus Theory analyzes how two sets of universal needs relate to each other, namely growth/development needs and security needs. The theory distinguishes between different conditions which can generate either positive emotions as a result of *gains* or negative emotions resulting from *losses*. Gains are defined as "the satisfaction or achievement of growth and development needs" and losses are understood as failure to satisfy security needs. In this framework there are two possible motivational orientations. Either promotion focus, which is about the pursuit of an ideal goal, or prevention focus, which is concerned about avoiding unpleasant outcomes. Usually individuals assume one of the two motivational orientations. (Stam & Stanton 2010)

Affective Events Theory offers a model for emotional experiences that identifies workplace events as triggers for emotional response in individuals and says that time plays a key role in the relationship between events, emotions, evaluations and behavior. The introduction of new technology can offer substantial benefits for some individuals in respect to productivity, career development and other benefits, while creating uncomfortable situations for others. Therefore new technology introduction can prompt both positive and negative emotions depending on the individual's motivational orientation. (Stam & Stanton 2010)

In the synthesis of the two theories Stam & Stanton (2010) postulate that an individual's positive or negative emotional reaction depends highly on the individual's personal goals and values and preferred state. Therefore a positive or negative emotional reaction is determined by how a workplace event impacts one's personal goals. Significant events at the workplace such as layoffs, promotions, raises and other such events have an effect on either development or security needs. Individuals tend to react to such events either positively (promotion focused) or negatively (prevention focus) and the behavioral response depends on the significance of the event. (Stam & Stanton 2010)

When an individual interprets events through promotion focus, this results into approaching behavior, while prevention focus results into avoidance behavior. Figure 7 depicts a graphical presentation of how events might unfold for a hypothetical worker in an organization. The behaviors have been divided into two phases: the preparatory phase and adaptive phase. Preparatory phase reflects the period of time before the actual technology has been introduced and made available while adaptive phase reflects on when an individual is able to either approach or avoid technology. (Stam & Stanton 2010)

Approach behaviors during the preparatory phase may include participating in developing specifications, vendor lists, and requests for proposals. Avoidance behaviors during preparatory phase include postponing, cancelling or skipping planning meetings and finding ways to slow down vendor selection process, or trying to convince coworkers that the new technology is unlikely to succeed. (Stam & Stanton 2010)

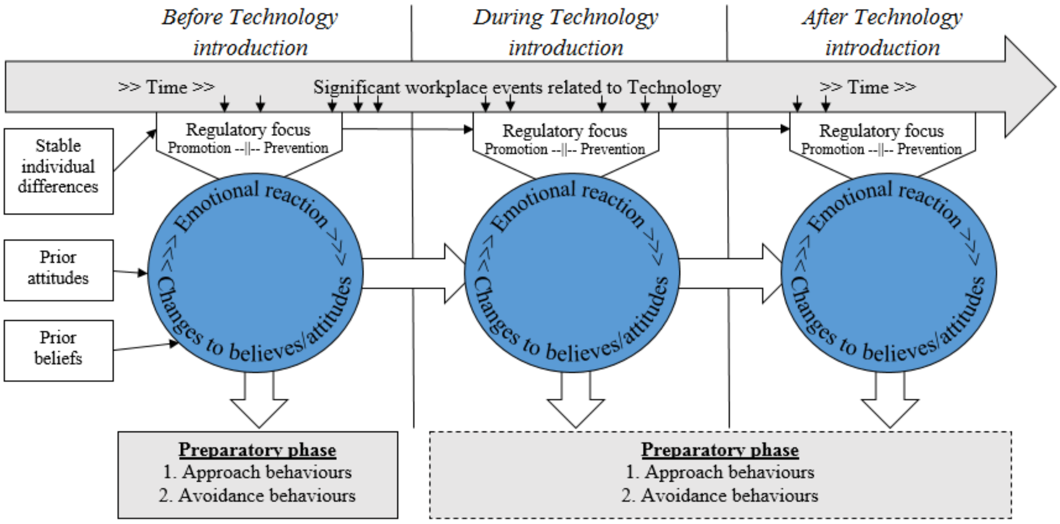

Figure 7. An emotion-focused model of adaptation to technology (adapted from Stam & Stanton, 2010)

3.3. Innovation diffusion theory

Innovation diffusion theory was developed by Everett Rogers in the early 1960s to describe at how and at what rate an innovation is gains momentum and spreads over time in a population. Rogers identified five types of adopters: innovators, early adopters, early majority, late majority and laggards. The distribution of each adopter type in a population follows a normal distribution which is demonstrated in Figure 8. (Rogers, 2003)

Innovators are venturesome cosmopolites who are obsessed with innovations. They understand and apply complex technical knowledge and can cope with high degree of uncertainty of innovations at the time of adoption. They take risks and are willing to accept setbacks when an innovation proves to be unsuccessful. Innovators play a key role in innovation diffusion process as gatekeepers by importing new ideas from outside to system boundaries. (Rogers 2003)

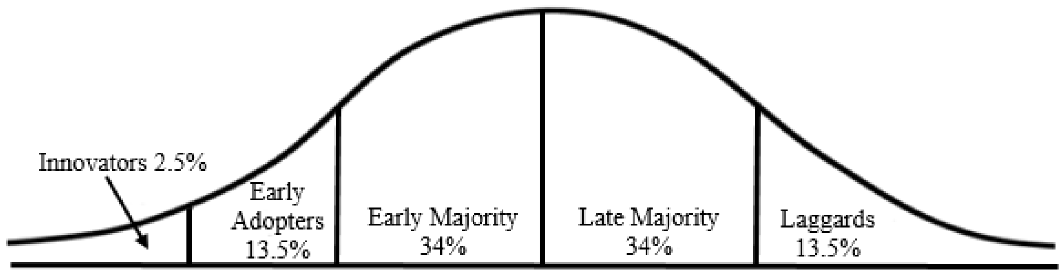

Figure 8. Adopter categorization on the basis of innovativeness (adopted from Rogers 2003)

Early adopters have a high degree of opinion leadership and are respected by their peers. Potential look to early adopters for advice and information about an innovation and they are often considered to be the people to check with before adopting an idea or innovation. They are often sought after by change agents as local ambassadors to speed up a diffusion process. Early adopters are not too far ahead of an average individual in a social system in innovativeness. Therefore they serve as role models for many other members of the social system. Early adopters help to trigger the critical mass when they adopt innovations. (Rogers 2003)

Early majority adopt new ideas just before an average member of a system. They interact frequently with their peers but seldom hold opinion leader positions in a community. The unique position between very early adopters and relatively late adopters and the critical mass of this adopter group make early majority an important link in the diffusion process. Early majority make a deliberate decision about completely adopting a new innovation. Making a decision on adopting an innovation or idea takes relatively longer than innovators and early adopters. They are willing to follow with deliberate willingness but seldom lead innovation adoption. (Rogers 2003)

Late majority adopt new ideas just after an average member of a system. They may adopt an idea out of economic necessity or peer pressure but usually approach innovations with skepticism. For late majority an idea must first be proven to work before they adopt an idea and they do not adopt until most peers in the system have already done so. (Rogers 2003)

Laggards are the last group of people to adopt an idea in a social system. Laggards possess no opinion leadership and their point of reference is the past. Their decision are often made based on how things have been done previously. Laggards tend to be suspicious of innovations and change agents and their adoption decision period is relatively long. Resistance to innovation from laggards may be completely rational from their point of view as their resources are limited and must know for sure that a new idea will not fail before they can adopt it. (Rogers 2003)

4 RESEARCH

For research purposes two surveys were performed in the Regensburg plant. The qualitative survey (Appendix 1) was aimed at production line managers where the aim was to understand what is their role in the organization, what tools, methods and KPIs are involved in their work, what challenges they face in collecting information for their work, what an imaginary new tool would ideally do and how they interact with their colleagues. The survey got the following amount of participations:

- 15 Focus Factory industrial engineers,
- 11 shift leaders,
- 1 line leader, and
- 9 system administrators.

The survey did not gather the minimum amount of 5 line leaders to participate in the survey which is required by German privacy laws for doing an analysis on them. This is why the role of line leaders in the organization will not be analyzed in this thesis. Also the analysis on interaction between colleagues will not be done because the collected data was not sufficient quality for drawing relevant conclusions from the analysis. The outcomes of this survey are explained from chapter “4.1. Analysis on Focus Factory industrial engineers” to chapter “4.6. The “ideal” Human-Machine-Interface”.

The quantitative survey (Appendix 2) was aimed at employees from operators to higher level managers who work directly on the targeted production floors where the aim was to gain understanding on what attitudes people have towards the concept of Industry 4.0, what is their experience level in using different technologies (smart phones, tablets, smart glasses, virtual reality glasses and smart watches), what is their attitudes towards the mentioned technologies and how they perceive their colleagues would react if the mentioned technologies were introduced to their work. The survey received 185 individual responses. Figure 9 shows the age distribution of the people who participated in the survey and Figure

10 shows the distribution of groups of people based on how long they have worked in their current position in Continental Automotive GmbH. The outcomes of this survey are explained from chapter "4.7. Familiarity with Industry 4.0" to chapter "4.10. Influence of past user experience on attitudes towards technology".

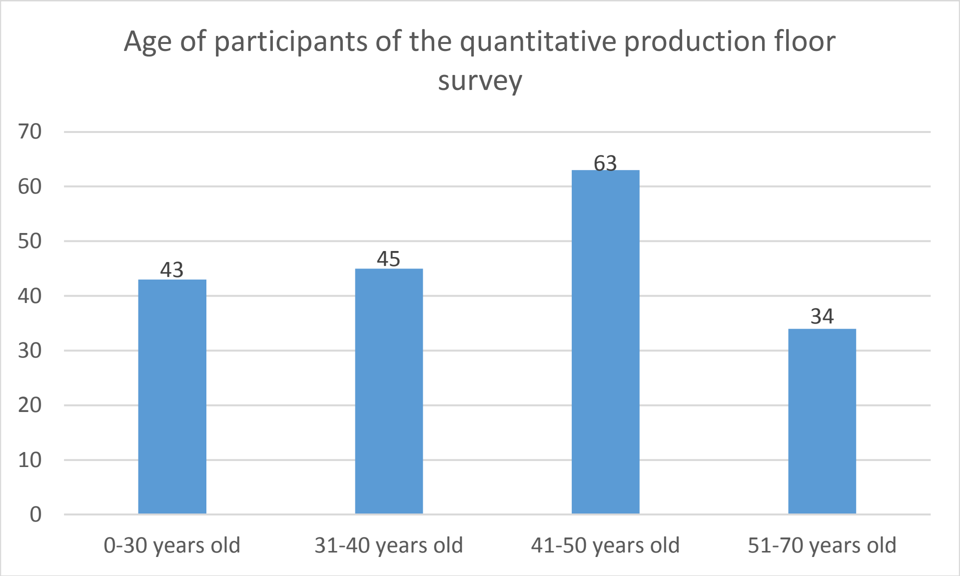

Figure 9. Age distribution of people who participated in quantitative production floor survey

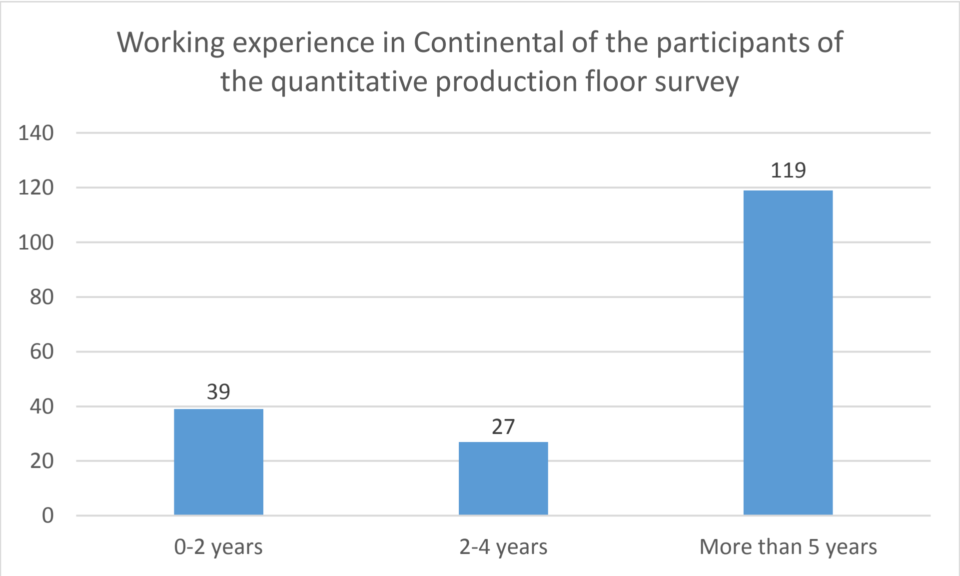

Figure 10. Experience distribution of people who participated in the quantitative production floor survey

4.1. Analysis on Focus Factory industrial engineers

In this chapter the survey answers given to the qualitative survey (Appendix 1) by 15 Focus Factory Engineers are processed to create a collective persona in order to gain an understanding on their responsibilities, tools and methods they use in their work and what they like and do not like about the methods and tools that they are using. Focus Factory industrial engineers work as a link between production floor and the higher management whose main responsibilities include continuous execution of process, plant and manufacturing optimization, supporting the production floor employees in problem solving when it is needed and supporting process planning and monitoring of the introduction of new processes, plants and production lines. They identify process weaknesses and implement related Six Sigma projects and initiate other improvement projects in order to develop parts of the processes that are not fully optimized. The most important Key Performance Indicators (KPI) they monitor at the production lines are Overall Equipment Efficiency, scrap, First Pass Yield and Total Equipment Efficiency Performance among other KPIs, such as maintenance costs and the number of work accidents in a given time period. They also give support in planning and execution of maintenance work, equipment calibration and improvement and they carry out cross-functional projects in cooperation with other departments and business units in Continental Regensburg.

In order to gather information for their work, the main methods Focus Factory industrial engineers rely on are discussions with colleagues, methodic trouble shooting, logical thinking, personal experience and data that is stored in logfiles in various databases. For data analysis the main tools they use are Six Sigma tools, production related tools, quality related tools and Excel. Sometimes when needed, they also use video surveillance of the machinery and employee surveys to gather more input for their analysis.

When asked what the Focus Factory industrial engineers like about their tools and methods, most commonly they mentioned that at least some of the tools they use provide a quick and clear presentation of the information they need with for example diagrams which can be generated with only little effort and used for the evaluation of the data. This way they can find errors quickly with the detailed data that is available in the logfiles they get from the production lines. With some individual tools the interface is understandable and clearly arranged for viewing the results of the analysis of the data. Additionally reviewing video surveillance recordings provides rich information on what is going on in the respective machine.

When asked what the Focus Factory industrial engineers do not like about their tools and methods, five main issues could be identified: too many complicated tools that are needed to track KPIs, manual data tracking, data quality, too many overlapping Excel data sheets and hardware performance issues. Many datasets are evaluated in separate complicated tools which are not compatible with each other and require deep understanding of each tool in order to be able to use them efficiently. Using these tools is viewed to be highly laborious and time-consuming and with the lack of training courses for some of the tools you need to use your own time to teach yourself how to use each individual tool. Additionally, it is said that it is not possible to have an overview of the most important KPIs in one glance and there is sometimes confusion about which tool you need to use to find the KPI or other information you are looking for.

Some participants of the survey also say that too many information boards are maintained manually either by handwriting or with printouts that need to be printed out every time there is a change in information. Often handwritten records are incomplete and contain errors and are time-consuming to maintain and in addition require double work when you have to maintain the same data digitally in various Excel documents. There are also quality issues with digital data when logfiles record necessary data only partially and there are no standardized specifications for what sort of data is generated and how they are generated. There is also a concern that there are too many Excel lists used which contain similar, if not the same, information which could be merged into one list.

Lastly, sometimes if there are hundreds, if not thousands, of data records that need to be displayed on the screen, certain tools take up to 30 minutes to load the data depending on the network or server load. In addition due to undefined constraints video surveillance is not always possible to do.

4.2. Analysis on shift leaders

In this chapter the survey answers given to the qualitative survey (Appendix 1) by 11 shift leaders are processed to create a collective persona in order to understand their responsibilities, tools and methods they use in their work and what they like and do not like about the methods and tools that they are using. Shift leaders keep track of their respective shifts in a number of production lines and make sure that the production lines run smoothly, work according to instructions, maintain standards, and that the staff is satisfied in their work. Shift leaders are responsible for assuring the quantity and quality of products produced in the production lines, managing man, machine and material usage in production lines and organizing maintenance of the production lines. In case of irregularities of production lines shift leaders are in charge of problem solving and decision making in the situation. In addition shift leaders manage the introduction of new production lines and are responsible for training, guiding and evaluating their employees as well as managing their holiday planning. Shift leaders also collaborate in rationalization and improvements in occupational safety and environmental protection.

The main KPIs shift leaders monitor are Overall Equipment Efficiency, First Pass Yield, scrap, maintenance costs, production output, throughput time and sickness rate of employees. In order to collect information for their work shift leaders rely on discussions with colleagues, variety of production related tools, quality related tools, Human Resources tools, logistics tools, Excel, shift transfers and shift books.

When asked what shift leaders like about their tools and methods, they mention simple user menus that are easy to navigate on at least one tool, non-distorted information they gain from direct discussion with their colleagues and resulting networking opportunities. They also mention that with the daily counts, analyses and meetings they are able to stay up to date and are able to react quickly to irregularities. On top of that most tools that are in use provide the possibility of staying up to speed about the activities around production floor without being personally present at the plant.

When asked what shift leaders do not like about the tools and methods they use in their work, three main issues could be identified: information overload, confusing tools and lack of overview. There seems to be an overflow of information that is hard to sort and manage and according to one participant of the survey the flood of information impacts the management of team meetings (MA-Gespräch) negatively. Similarly to Focus Factory industrial engineers some shift leaders are dissatisfied that you need to have a deep understanding of a tool before you can start using it efficiently. Some of the desired information cannot sometimes be accessed because of lack of authorization and you might need to wait for someone with a higher authorization to be present before you can access a piece of information you are looking for. It is mentioned that sometimes Excel based data tracking is very confusing because you can only view one system at a time and sometimes you have to search for data from several Excel files.

There is a lack of overview because there is not any singular tool that shows all key figures in one display. When looking for information you have to search through several tools which is found to be time consuming and frustrating. It is mentioned that if you want to see all data produced by one machine you have to open and search for information in up to 8 tools. On top of the main issues some people mention that sometimes in the late shift some key specialists cannot be reached and that the WLAN does not reach all parts of the factory which means that you cannot access the drives and/or databases with phone in some parts of the production floor.

4.3. Analysis on system administrators

In this chapter the survey answers given to the qualitative survey (Appendix 1) by 9 system administrators are processed to create a collective persona in order to understand their responsibilities, tools and methods they use in their work and what they like and do not like about the methods and tools that they are using. System administrators are responsible for the maintenance and repairing of production equipment in order to maintain, increase and improve plant availability, and cyclical calibration of production equipment. They manage employees, spare parts, material supply and production output and document production quantity, quality and trends in production on to the respective line information boards. Additionally they accompany new product and production line launches and provide support to employees, production, Focus Factory industrial engineers and parallel departments.

The main KPIs system administrators track in their work are Overall Equipment Efficiency, scrap, First Pass Yield, Internal Defect Rate and maintenance costs. The main sources of information for system administrators are line performance meetings, training courses for managers, a variety of production tools, quality tools and Six Sigma tools. Additionally they use Microsoft Office tools, such as Excel, databases and logfiles in their work and sometimes also video surveillance in trouble shooting.

When asked what system administrators like about their tools and methods, they mention that human communication and some tools provide a fast way of gathering information and data, digital tools can be used directly from computers with close to no additional paperwork required and that some unnamed tools are very clearly arranged and easy to use. On top of this Six Sigma methods are found to be a relatively easy way to find the cause of a problem and a solution to it. When asked what system administrators do not like about their tools and methods, they mention that some of the generated data is not complete and/or have to be generated on the spot when there are problems and the logfiles do not have any standard format, resulting into data that is hard to compare with other logfiles. Most tools and tables are not interlinked and you might need to enter the same information into more than one tool. Some dissatisfaction on recording special cases, such as malfunctions, on paper was also expressed.

4.4. People’s satisfaction with existing Human-Machine-Interfaces

In the management survey (Appendix 1) production line managers were asked to describe the HMIs that they use in their work and explain what they like and do not like about using them. In this chapter the respective answers are processed to investigate what production line managers are satisfied with while using the HMIs and what they are not satisfied with in order to figure out what features to keep and what problems need to be addressed in the next generation HMI that will be developed in the future. In this analysis all answers are collected together and categorized in order to identify positively perceived features of the existing HMIs, that should be kept, and challenges that need to be addressed in the next generation HMIs. Based on the identified positive features and existing challenges a list of requirements will be created. It has to be noted that survey participants are not necessarily describing the same HMI, but a range of HMIs they personally use, which might lead to conflicting information.

When production line managers were asked what they like about the HMIs they use, the following positive features could be identified:

- *Intuitive operation*: operating elements are designed logically and clearly.
- *Adaptability*: the interface can be adapted because of flexible programming which allows the interface to be supplemented and adapted.
- *Easily accessible information*: an overview of most important KPIs can be accessed almost at any time and it is easy to follow the progress of the current production.
- *Good visualization*: optical status lights (for example traffic lights) displayed on an interface enable quick reactions to standstills and irregularities in production. The visualization also shows what procedure needs to be followed.

When asked what production line managers do not like about the HMIs they use in their work, several challenges could be identified. First there are *technical problems*. Often it takes a long time to load the data that needs to be evaluated and sometimes even the smallest deviations cause standstills and system failures. Secondly there is a *lack of training* for using some of the control panels. Control panels can be operated quickly and effectively only after training courses and/or studying the control panels on your own. Thirdly, there are *too many interfaces at the production lines*. For example when you are changing a product in a production line, you must use a different computer instead of simply entering the information of product change in the interface. Fourthly, there is *out-of-date or inaccessible data*. Not all of data can be found maybe because a lot of times the data is not completely synchronized and sometimes there is a lack of authorization to access data, in which case work is slowed down because you need to wait for someone with a higher clearance to be present. Fifthly, sometimes depending on the application there are *no variable input options* which means that the machine is not adapted to the need. Lastly, *not all systems are visualized the same way*. For example, some systems are monochrome instead of displaying information with colorful traffic lights for example.

From the identified positive features and challenges we can derive the following list of requirements that the next generation HMIs must fulfill:

1. Interfaces must be logically and clearly organized for easy navigation and understandable visualization.
2. Interfaces must be customizable for personal preferences.
3. Interfaces must provide an easily accessible overview of the most important KPIs.
4. Interfaces must provide a quick overview of the status of the production line.
5. Interfaces must display the data within a short time period.
6. Interfaces must provide support in making using the system more understandable.
7. Interfaces must be able accommodate to changes in the production (for example when there is a change in the product that is produced in the production line).
8. Interfaces must be able to display up-to-date, synchronized data.
9. Interfaces must have variable input options.
10. Visualizations of the interfaces must be uniform and standardized.

The word choice of “must” is deliberate because evaluation of relevance and prioritization of the requirements happens in the requirements analysis phase of the

RE process. Prioritization of the requirements is not within the scope of this master thesis and the refinement will be the responsibility of the future HMI development team.

4.5. Existing challenges in information collection

In the management survey (Appendix 1) production line managers were asked about the most common obstacles they face when gathering information in their work. In this chapter the answers will be broken down, clustered into groups and analyzed in order to derive underlying needs of production line managers that need to be addressed. In the end additional requirements for HMIs are derived where applicable.

From the survey answers several obstacles could be identified. Most common obstacle is the *unreliable data*. Logfiles are often incomplete and/or inaccurate because necessary information is not always written correctly if at all. Sometimes it is not clear where some data is stored and there is doubt about if some data records exist at all and from time to time important additional information, such as the date/time or a serial number of a produced device, is missing. Second most commonly mentioned obstacle is that *there are too many complicated evaluation tools that operate differently from each other*. The tools are confusing to use and do not provide any overview of all of the information you need and you often have to switch between different tools to gather all the information that you are looking for. Additionally, there is a lack of instructions and training on how to use the necessary tool and unless you are already fluent with the tool you are using, you lose a lot of time just trying to navigate around the program. Thirdly, *loading data takes too long* because sometimes the used tools are not powerful enough to process the large amount of data that needs to be evaluated. Fourthly, *unclear and decentralized data storage*. There is a huge network of data storage locations and the filing structures are found to be confusing as all data is widely distributed. There is a lack of a single database with a clear structure that is easy to navigate and where you know where to look for specific information in a single folder or file that does not overlap with other folders or files in their content. Fifthly, there is *no* *standardization of data output*. According to the survey participants, different software create different kinds of data without a standardized format and it can be confusing to figure out how to find certain information from different data sets.

Non-data related obstacles include slowed down information flow due to inadequate official communication channels, lack of availability of key people you need information from, lack of communication between shifts and for some people the overflow of non-priority e-mails they receive. On top of that some software often experience bugs while in use and there is some bureaucracy involved when trying to get things approved and implemented. Also there is no information on how an error in a production line has already been fixed in the past.

Based on these observations we can derive the following needs of production line managers:

- There is a need to have access to complete and up-to-date data.
- There is a need to decrease the amount of tools that are used or at least provide proper support in learning to use them.
- There is a need to access data with minimal time needed to wait for the data to load on the display.
- There is a need to have clarity on where you can access the data that you are looking for.
- There is a need for uniform data output that can be evaluated easily.

Additionally, we can derive the following requirements for HMIs from the analysis:

1. Interfaces must produce complete and up-to-date data.
2. Interfaces must be simple to use.
3. Interfaces must have an overview of the most important KPIs.
4. Interfaces must load data on display with minimal waiting time.
5. Interfaces must store their data in a location from where they can be easily retrieved.
6. Interfaces must produce data in a standardized format.
7. Interfaces must provide information on how an error has been fixed.

From the derived requirements we can see that there is an overlap with the ones developed in the previous chapter. This will be evaluated in chapter “5.2. Requirements development”.

4.6. The “ideal” Human-Machine-Interface

In the management survey (Appendix 1) production line managers were asked “A new tool is introduced to make your work easier. What would it ideally do? What functions would it have?” and “How would this help to improve your daily work?” Context or any restriction on the purpose of the imaginary tool was purposefully not given for two reasons. Firstly, there should be no boundaries set on thinking when you are trying to collect creative ideas and solutions. Answers from this question can be used as a starting point for the Ideation phase of the Design Thinking process. Secondly the answers can be used to analyze non-explicit needs respondents have. In this chapter the answers to these questions are processed and analyzed in order to discover underlying needs from people’s wishes for a new tool. Based on the needs, additional requirements will be derived at the end of this chapter.

Based on the analysis of the survey answers (Appendix 3), several types of user needs could be identified, namely: data related needs, accessibility needs, usability needs, need for a good overview and communication related needs.

Data related needs: There is a need to have access to automatically generated high quality and reliable data that is easy to understand and is automatically evaluated by the software. The data should be live and up-to-date, and there should be for example data available on past failures in the production line. The imaginary tool should enable a diverse way of displaying data with graphics for example.

Accessibility: There is a need for a tool which can access the internet and can be used to access data folders. Accessibility to data, evaluation tools and file folders should be non-location dependent and should enable remote access outside of the production floor, for example in management meetings or home office.

Usability: There is a need for a high performing lean tool that loads data fast, is easy to navigate and is compatible with other tools. It should be customizable for personal use and provide adequate support and instructions in using it and for example provide an overview of available training courses. It should be possible to write variable inputs digitally to the production system even if you are not on the location.

Overview: There is a need for a tool which replaces the high amount of Excel sheets that are currently being used and possibly also replaces existing evaluation tools in order to decrease the need to switch between multiple tools in order to make it easier to have a good overview of the most important KPIs. Automatic KPI calculations should be integrated in the tool which should be possible to evaluate digitally without any hand-written input.

Communication: There is a need for a tool which facilitates easier communication between colleagues through a communication platform where you can share photos, files and other work related materials. It should be possible to communicate with colleagues without the need to use personal phones or other devices.

When asked how the survey participants would expect their imaginary tool to improve their job performance, they said that it would be possible to have a faster overview of an ongoing situation and enable faster reaction time and trouble shooting. It is expected that there would be a lot of saved time and overall more efficient working. Access to correct information would be faster which would make problem analysis easier. It would also make the work easier when using the tool is supported in a sufficient way.

It has to be noted that the tool described above is an ideal work of imagination and in the future development steps you need to evaluate the technical feasibility, resource capacity and what regulations are there that could prevent realizing some of the features. It is not expected that you would be able to produce a solution that answers all of these needs, but it could be possible to create a smaller solution that addresses a portion of the needs described above. Evaluation of feasibility and constraints is done in the requirement analysis phase of RE process, and when following DT process, the next step would be to critically evaluate each idea (Appendix 3) to decide which ideas will be refined in the next step.

From the analysis we can derive the following requirements:

1. Interfaces must produce high quality and reliable data.
2. Interfaces must do automatic evaluation of the produced data.
3. Interfaces must produce live data.
4. Interfaces must show data on past failures.
5. Interfaces must enable displaying data in a variety of ways.
6. Interfaces must have online access.
7. Interfaces must enable remote access to data folders irrespective of the user’s physical location.
8. Interfaces must enable remote access to evaluation tools irrespective of the user’s physical location.
9. Interfaces must be able to load data in a short time period with minimal resources.
10. Interfaces must be easy to navigate.
11. Interfaces must support the user in using the interface.
12. Interfaces must enable digital input.
13. Interfaces must show an easily accessible overview of the most important KPIs.
14. Interfaces must have integrated KPI formulas.
15. Interfaces must make it possible to share photos and files.

Further evaluation of all requirements will be done in chapter “5.2. Requirements development”.

4.7. Familiarity with Industry 4.0

Industry 4.0 and digitalization has been a hot topic across industries for several years. As a part of the quantitative survey (Appendix 2), people working on the targeted production floors were asked if they are familiar with the concept of Industry 4.0 and what is their attitude towards it. This was done in order to get an indication of how willing people would be to participate in Industry 4.0 related initiatives, such as introducing mobile and portable devices into the production work flow. Analysis on this is done in two parts: familiarity and attitudes depending on age (Figure 11) and familiarity and attitudes depending on how long a person has worked in the company (Figure 12).

What can be seen from Figure 11 is that the majority of production floor employees have at least heard of the concept of Industry 4.0 and the general attitude towards it does not vary significantly between age groups. On average around 40% of the survey participants view Industry 4.0 in a positive light whereas skeptics constitute of roughly 10-20% of the survey participants. The reasons for differences in attitudes can vary from level of education, the respective work function and perception on how Industry 4.0 is working in Continental at the moment. Curiously enough people in the 31-40-years-old tend to be more neutral on the subject than the other age groups.

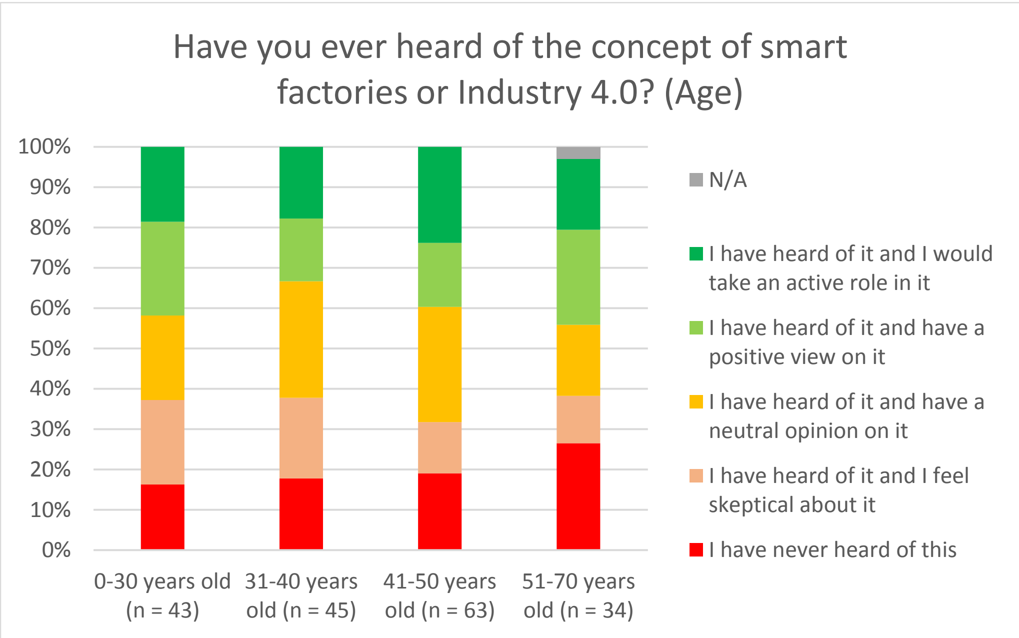

Figure 11. Familiarity and attitudes on Industry 4.0 based on age

In Figure 12 we can see more significant differences. Most people who have not heard of the concept are non-surprisingly people who have entered the company in the last two years. Oddly enough 20% of people who have worked in the company for more than five years, which represents majority of the survey participants, have not heard about the concept either. Other than that, no major differences can be identified from this analysis.

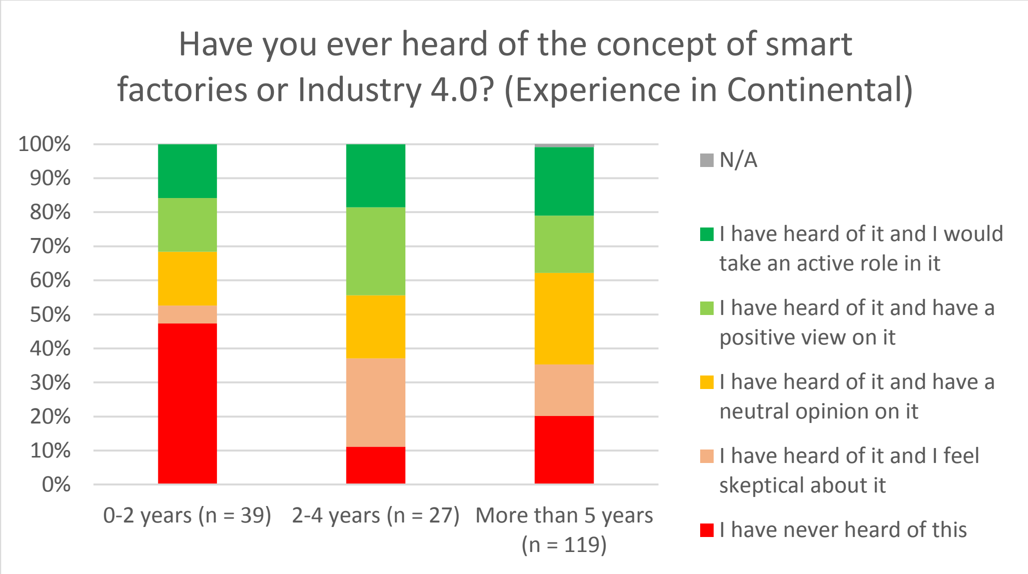

Figure 12. Familiarity and attitudes on Industry 4.0 based on working experience

What can be concluded from this analysis is that most employees are aware of the concept of Industry 4.0 and the opinions are rather divided. It might be a good idea to interview people personally and ask why they hold their respective attitudes on the subject and investigate if there is a need to clarify anything in their minds. What has to be considered is that most people, who participated in the quantitative survey, do not hold management positions, so they might not be involved in strategic discussions which is more central on the management level.

4.8. Analysis on employees' experience in using smart devices

A qualitative survey (Appendix 2) was conducted to investigate how experienced people are in using technology that is today available on the market and could potentially be integrated into the production floors as a part of production floor digitalization initiatives. This was done in order to gather an indication of the level of effort expectancy related to different smart devices such as smart phones, tablets and others that are on the market. Experience is used as an indicator of ease of use since we can expect that with increased level of experience using a technology becomes easier, therefore having less change resistance if such technology is introduced. In this chapter the results are broken down and analyzed.

In Figure 13 we can see the breakdown of experience in using the devices included in the survey. Majority of people have experience in using smart phones and tablets and many of them use one on a regular basis either because they own one or have had access to one previously. On the other hand only few people use smart glasses, VR glasses or smart watches on a regular basis. While majority of people have heard about all of the respective technologies, a vast majority has never experimented with them. Smart glasses seem to be the least familiar technology among the people surveyed.

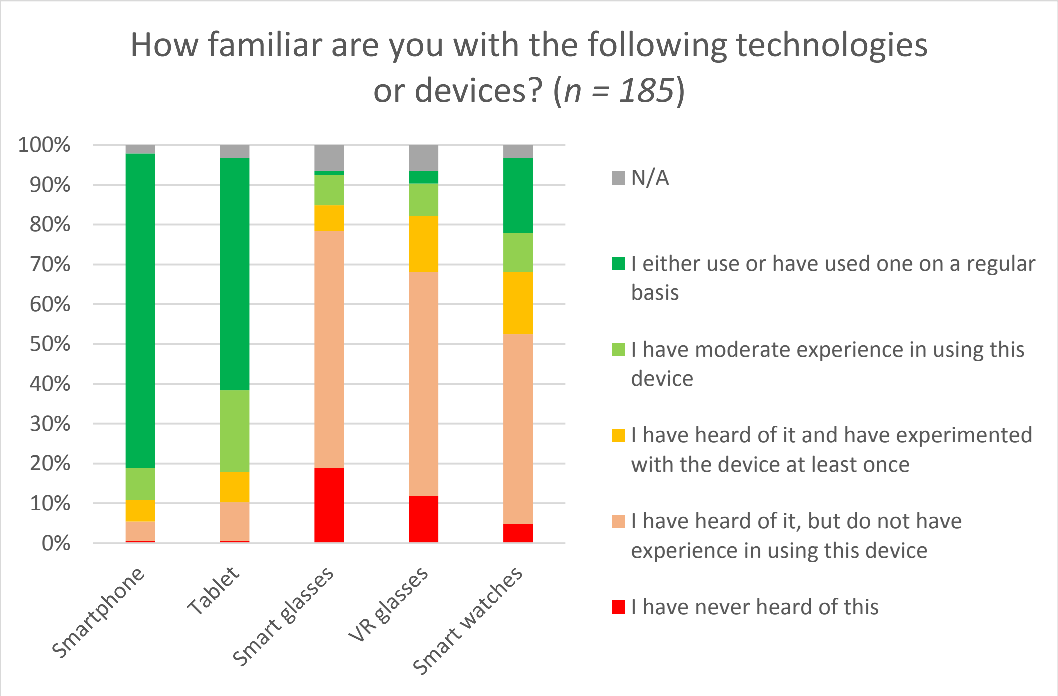

Figure 13. Experience levels of using smart devices among production floor employees (average)

On average roughly 87% of survey participants have at least moderate experience in using smart phones compared to 79% for tablets, 9% for smart glasses, 11% for VR glasses and 29% for smart watches. 10% of survey participants have heard of but have little or no experience in using smart phones compared to 19% for tablets, 66% for smart glasses, 70% for VR glasses and 63% for smart watches. <1% of participants have never heard of smart phones compared to <1% for tablets, 19% for smart glasses, 12% for VR glasses and 5% for smart watches. These numbers will be used as a reference when we do comparison between age groups.

The same analysis is done for each age group to see if there are significant differences between generations. From Figure 14 we can see that compared to the average population 0-30-year-olds do not differ significantly in terms of experience with using smart phones, tablets or VR glasses. People with at least moderate experience in using smart glasses is proportionally the same while 75% of people are at least aware of the technology while having little to no experience using it (average 66%). All surveyed 0-30-year olds have at least heard of smart watches and roughly 37% have at least moderate experience using (average 29%).

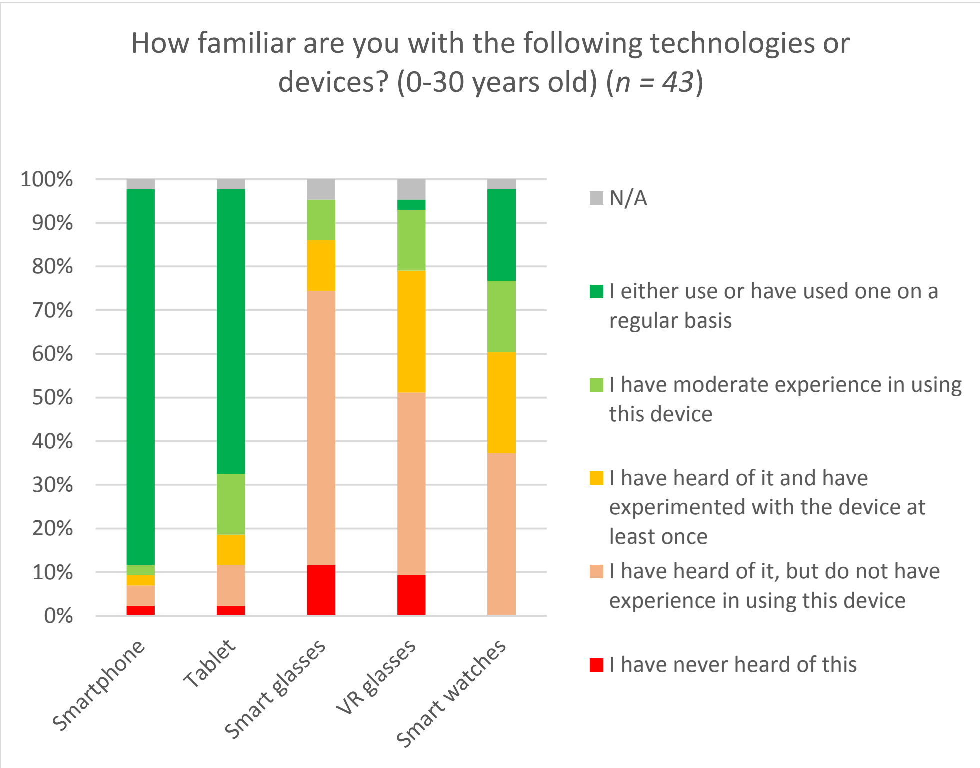

Figure 14. Experience levels of using smart devices among production floor employees (0-30 years old)

From Figure 15 we can see that 31-40-year olds do not show any major differences to the average population in terms of awareness and experience of using any of the devices included in the survey. In Figure 16 the same can be observed for 41-50-year olds with the exception that proportionally fewer people have at least moderate experience of using smart watches (roughly 22%) compared to average (29%).

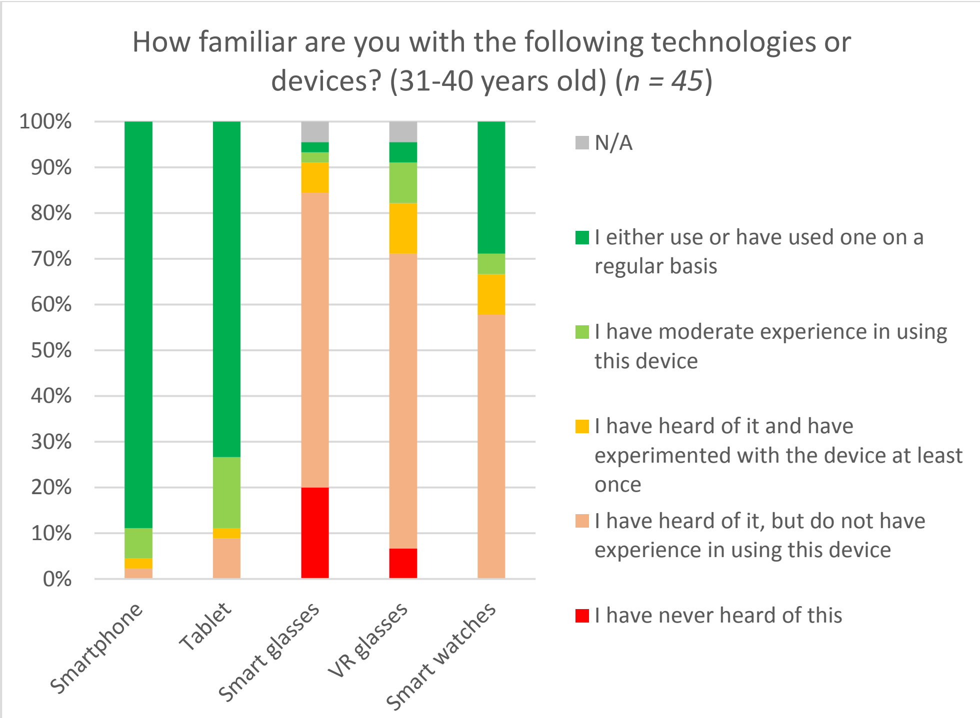

Figure 15. Experience levels of using smart devices among production floor employees (31-40 years old)

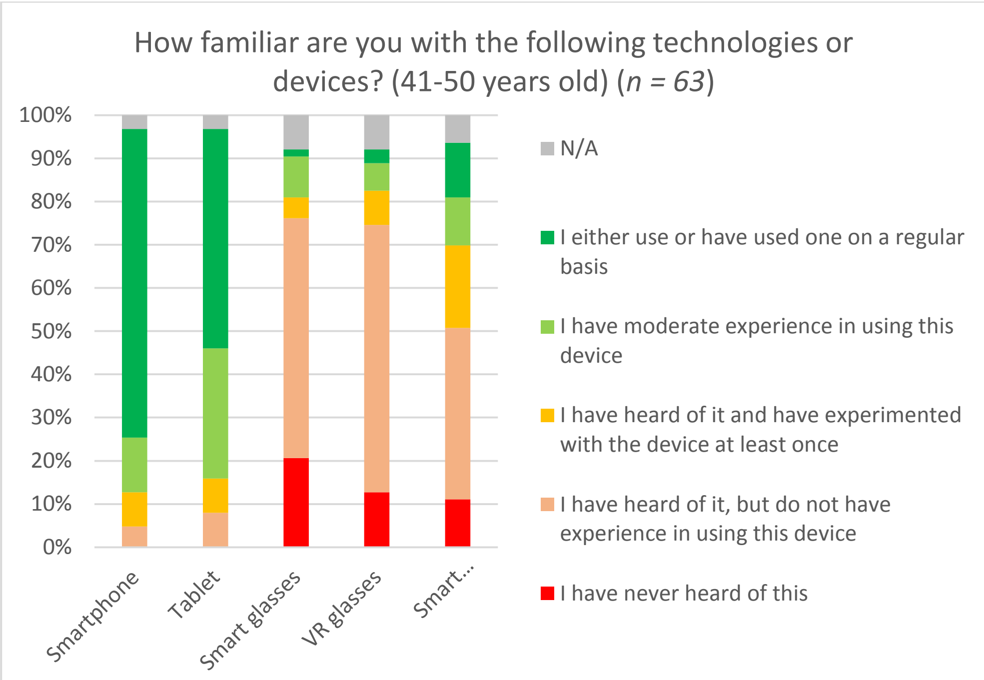

Figure 16. Experience levels of using smart devices among production floor employees (41-50 years old)

From Figure 17 we can see that having at least moderate experience with smart phones is proportionally less common (80%) compared to average (87%). 60% of survey participants in this age group say that they have moderate experience with tablets (average 79%). Same trend can be seen for smart watches with roughly 20% of people having at least moderate experience with it compared to the average of 29%. Lack of awareness of VR glasses is proportionately higher (20%) compared to other age groups.

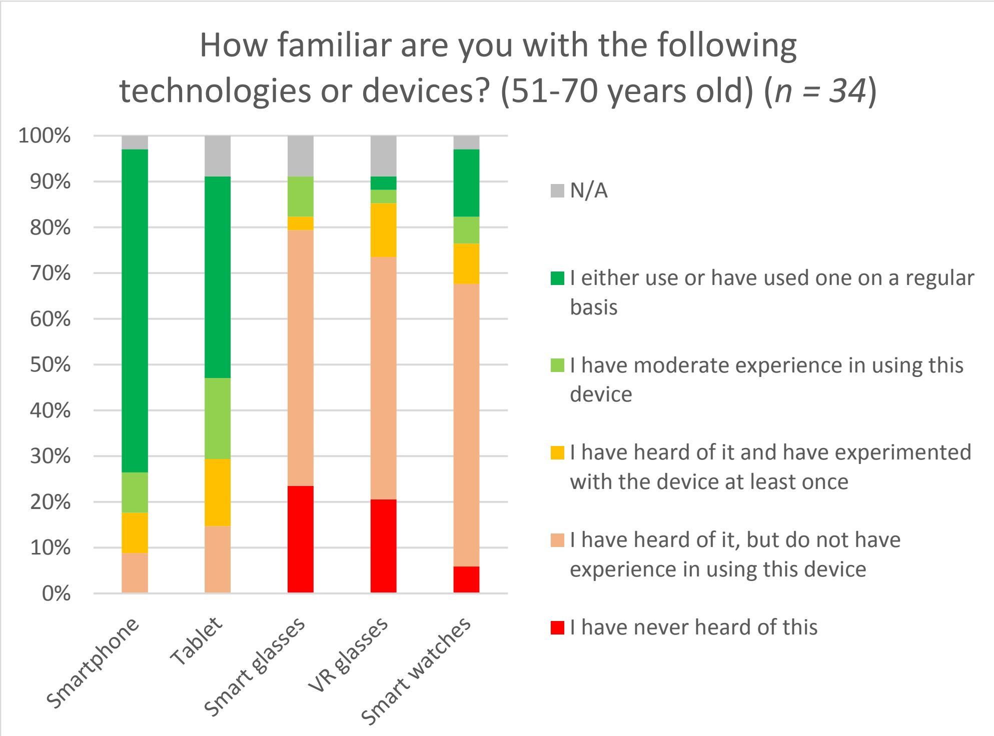

Figure 17. Experience levels of using smart devices among production floor employees (51-70 years old years old)

We can make the following conclusions:

- Smart phones and tablets are very common across all age groups with no significant differences.
- Experience with smart glasses and VR glasses is rare and there are no major differences between age groups.
- Smart watches are significantly more common among under 30 year olds than in other age groups.
- In older age groups having experience using the more common smart devices is less common than for other age groups on average.

4.9. Analysis employees' on attitudes towards smart devices

A qualitative survey (Appendix 2) was conducted to investigate how willing people would be to integrate technology that is today available on the market to their work, if it was introduced. This was done in order to gather an indication of the level of performance expectancy related to different smart devices such as smart phones, tablets and others that are on the market. The thinking behind this question is that if you are open minded about integrating any tool that is introduced to you, you are more likely to expect it to be useful in your work. In this chapter the results are broken down and analyzed.

From Figure 18 we can see that most people either already use or would use smart phones and tablets in their work if they were given the option. Smart glasses and VR glasses receive most skepticism while smart watches on average split people in half with half of the respondents being favorable and the other half being uncertain or against integrating smart watches in their work.

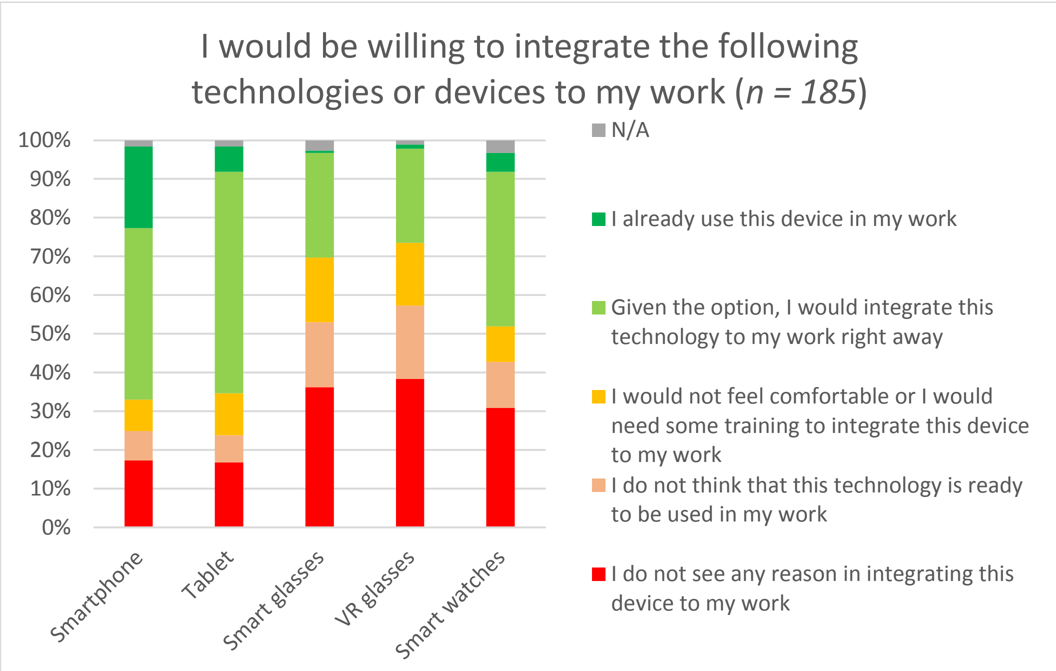

Figure 18. Willingness to integrate new technology into work (average)

On average 65% of survey participants either already use or would use smart phones in their work compared to 64% for tablets, 28% for smart glasses, 25% for VR glasses and 45% for smart watches. 8% of survey participants would feel uncomfortable or would need training using smartphones in their work compared to 11% for tablet, 17% for smart glasses, 16% for VR glasses and 9% for smart watches. 25% of survey participants are skeptical and either do not see any reason in using smartphones or do not feel that the technology is ready compared to 24%

for tablets, 53% for smart glasses, 57% for VR glasses and 43% for smart glasses. These numbers will be used as a reference when doing the analysis by age groups.

From Figure 19 we can see that among 0-30-year-olds there are no major differences in willingness to integrate smart phones or tablets into their work compared to the average survey participant. For smart glasses there is a proportionately more positive view (35%) on integrating smart glasses compared to average (28%) and there are also less skeptics (45%) compared to the average (53%). 0-30 year olds are more skeptical about VR glasses (65%) compared to average (57%) and on the other hand they are more open about using smart watches (55%) in their worked compared to the average (45%).

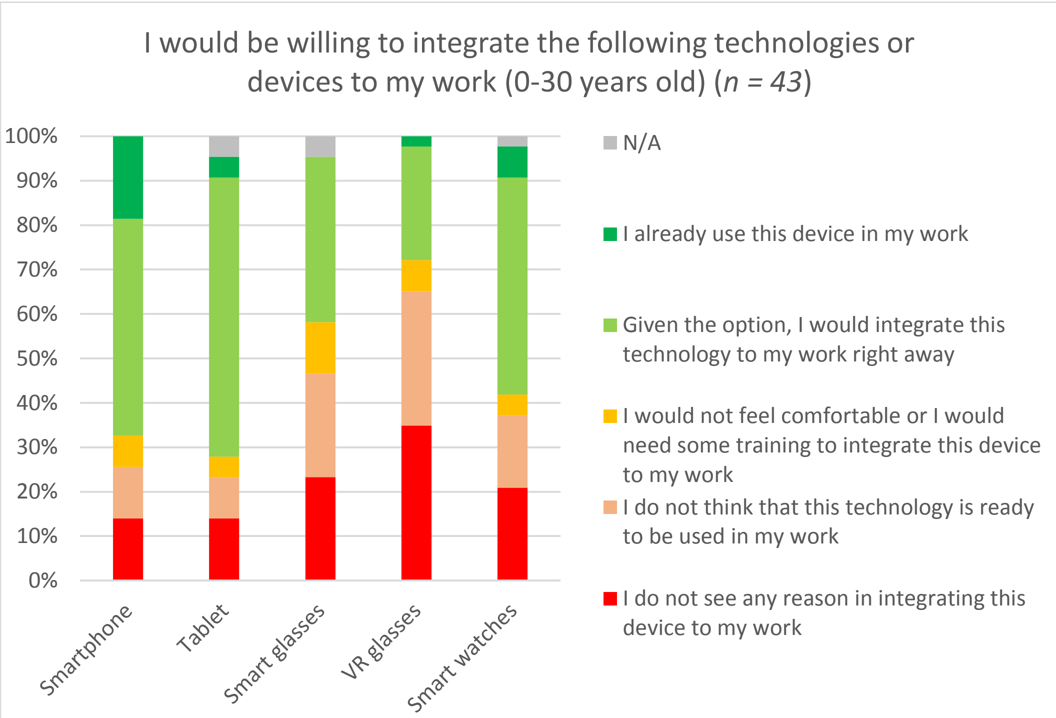

Figure 19. Willingness to integrate new technology into work (0-30 year olds)

From Figure 20 we can see that a higher proportion of 31-40-year-olds would be willing to integrate smartphones into their work (80%) compared to the average (65%). Same thing can be seen for tablets (80%) compared to the average (64%). For smart glasses and smart watches there are no major difference to the average opinions of the survey participants. There is less skepticism about VR glasses (51%) compared to the average (57%).

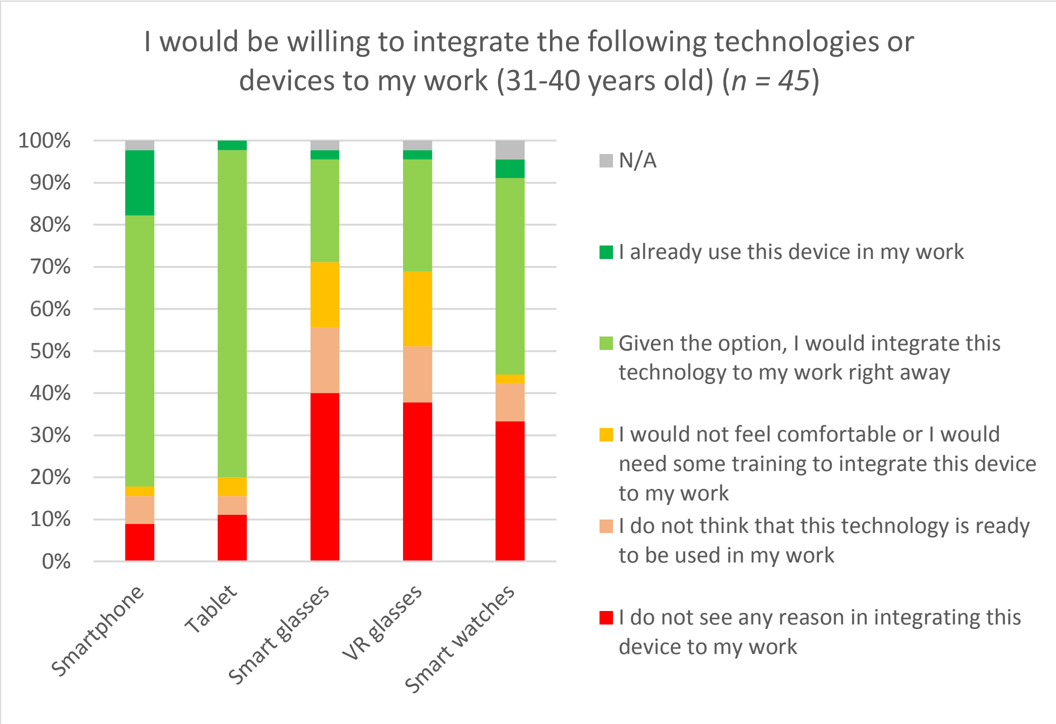

Figure 20. Willingness to integrate new technology into work (31-40 year olds)

From Figure 21 we can see that among 41-50-year-olds, other than being slightly more open minded about integrating VR glasses (30%) into work compared to the average (25%), there are no significant differences to the average of all age groups.

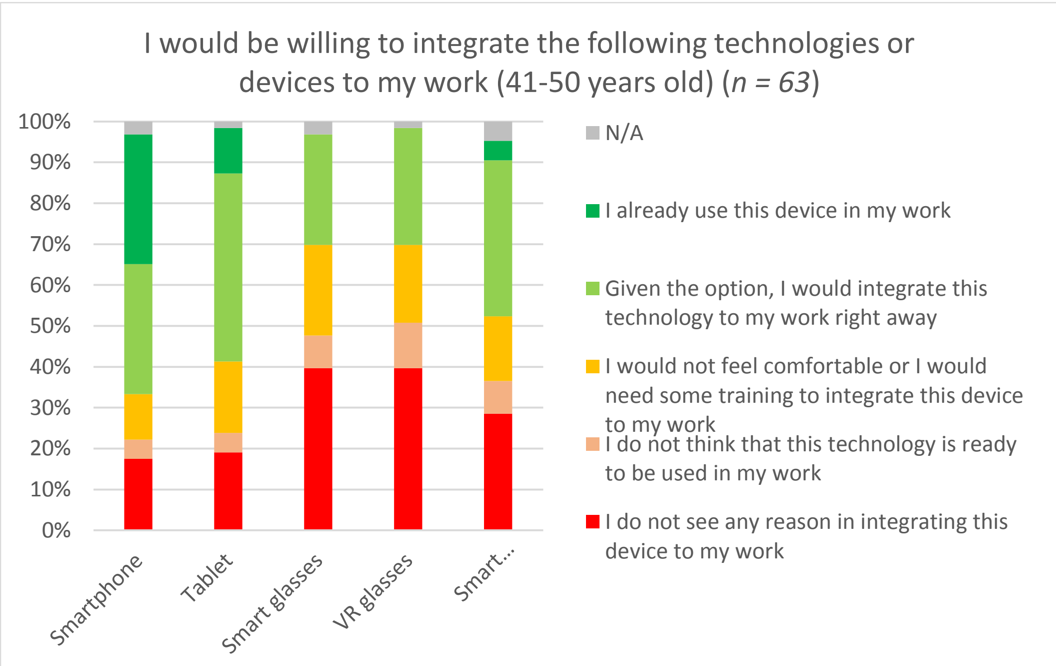

Figure 21. Willingness to integrate new technology into work (41-50 year olds)

From Figure 22 we can see that among 51-70-year-olds there is a lot more skepticism across the board compared to the average. 50% of survey participants in this age group either already use or would use smartphones into their work (average 65%) while 40% are against the idea (average 25%). 50% of survey participants in this age group either use or would use tablets in their work (64% average) while 35% are against the idea (24% average). 15% of of survey participants in this age group either use or would use smart glasses in their work (28% average) while 68% are against the idea (53% average). 25% of survey participants in this age group either use or would use smart watches (45% average) while 61% are against the idea (average 43%).

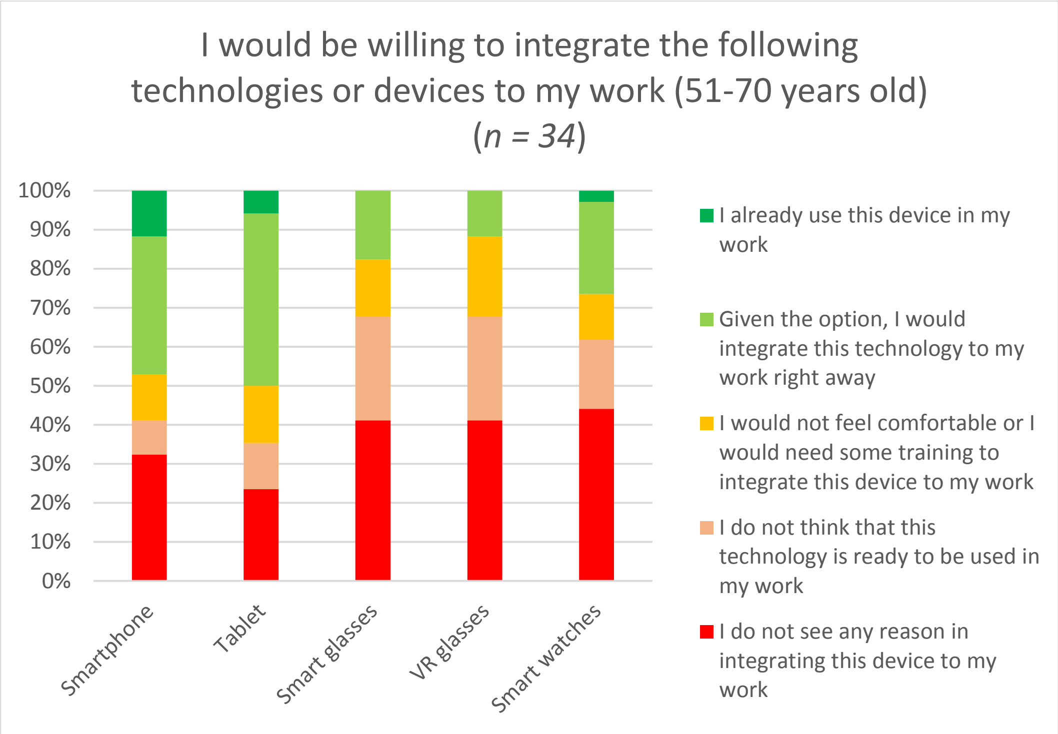

Figure 22. Willingness to integrate new technology into work (51-70 year olds)

From this analysis we can conclude:

- For smartphones there are no significant differences of opinion across different age groups with the exception that 31-40-year-olds are more likely to either use or willing to use them in their work.
- Young people view integrating smart watches more favorably compared to other age groups, are less skeptical about smart glasses than other age groups but are more skeptical about VR glasses than others.
- 31-50-year-olds are more open minded about integrating VR glasses into their work compared to other age groups.
- 51-70-year-olds are clearly more skeptical about all technologies compared to other age groups.

In the same qualitative survey (Appendix 2) there was a question about how they perceive what their colleagues would think if a respective technology was introduced into their work. In Figure 23 we can see the distribution of perceived opinions of colleagues which follow the same trend as we have seen in people's own willingness to integrate technology. People mostly believe that smart phones and tablets would be viewed slightly positively or very positively while this is less of the case for the other devices. More skepticism is granted for smart glasses and VR glasses but mostly people believe that the opinions would either be neutral or mixed. What we can speculate from this is that most likely people believe that there would be no strong emotions in either direction if these devices were introduced. No significant differences between age groups were found on this question.

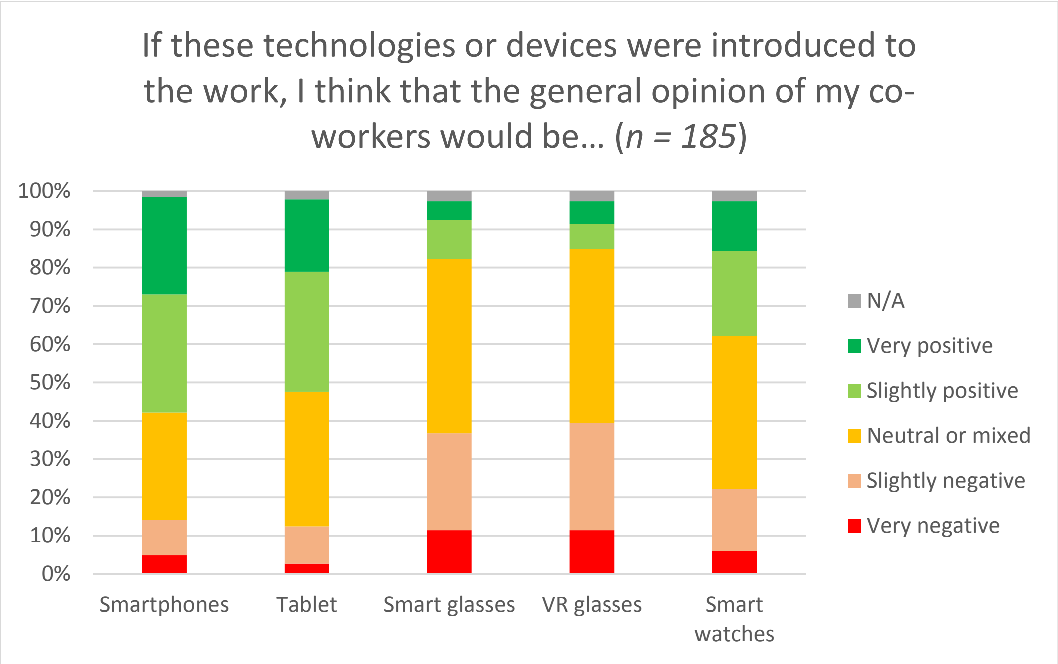

Figure 23. Perceived opinion of colleagues on technology introduction

What was interesting to observe, while processing the raw data of the survey, was that there were several survey participants who were open to trying or using all artifacts of technology even if they had no previous experience in using it and also a number of people who were skeptical or down right against all technologies. This seems to be consistent with innovation diffusion theory which divides each population into innovators, or risk takers, and laggards, or skeptics, which represent opposite extremes of a mindset towards new ideas. What this survey did not show was the reasons behind people's attitudes. While all of these technologies are relatively available, it can only be speculated if openness or skepticism towards using a technology is more related to the curiosity of different individuals towards using technology, seeing potential gains or losses of using technology depending on if you have promotion or avoidance focus, or if you are more open to trying new ways of doing things or are more conservative and want to stick with to the routines you are used to. It can also be a combination of all of these things.

However, the majority of the survey participants showed a mixture of attitudes towards using individual technologies which depended on how familiar they were already with the devices. This will be elaborated in the next chapter.

4.10. Influence of past user experience on attitudes towards technology

This chapter explains the results of a cross-analysis on how one's own experience in using a smart device, or the lack of it, influences a person's attitude towards integrating the device into their work. How the analysis was done was that the survey answers from the question of how experienced people are with using a device were taken and checked with the answers of their willingness to integrate the device in their work, eg. how many people who have moderate experience using tablets would be willing to integrate in their work. For the clarity of the analysis, two groups of people were excluded from the data: those who say that they already use a device and those who left an answer blank in one of the two questions. The reasons are that it makes no sense to analyze the open mindedness of using a device if they already use it and if someone left one or both question unanswered the data is not valid for the purpose of this analysis.

From empirical analysis, presented in Figure 24, we can see that the relationship between one's past experience in using an artifact of technology and one's openness towards the idea of integrating it into one's work, if it is not already in use, has a positive correlation. This means that the more proficient you are with using a device, the more likely you are to have a positive view towards using it in your work, if you do not already use it. And vice versa, if you have no knowledge on an artifact of technology, you are more likely to be against the idea of using it in your work.

Though this might not seem surprising, what is an interesting finding is that having experimented with an artifact of technology at least one time before has a significant positive impact on your view on the idea of integrating the technology into your work as opposed to knowing about it, but never having experimented with it. This gives a strong indication that in order to be have better chances in convincing someone about using a non-familiar technology, you should let the person experiment with the technology before the official introduction of the technology to the workflow. This way they can base their opinions on the technology on their own experience rather than what they heard or read about it in various sources.

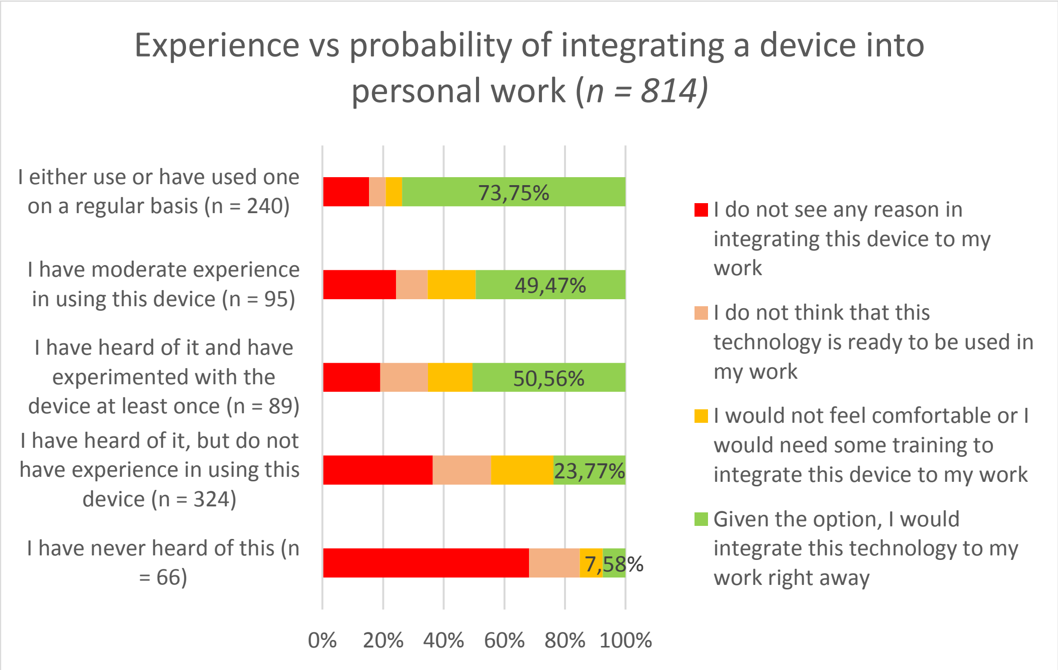

Figure 24. The effect of past experience in using a device in the willingness of integrating it to the work

5 RESULTS AND EVALUATION

In this chapter the outcomes of the research are summarized and further evaluated. In chapter “5.1. Problem analysis” the key issues and user needs are identified to give an overall picture of the situation on the production floors. In chapter “5.2. Requirements development” the developed requirements in chapters “4.4. People’s satisfaction with existing Human-Machine-Interfaces”, “4.5. Existing challenges in information collection” and “4.6. The “ideal” Human-Machine-Interface” are collected together and evaluated for how they should be further processed and analyzed. In chapter “5.3. Priority list for future development projects” final conclusions on the results of quantitative survey are made in order to evaluate which smart devices would be easiest to introduce into the workflow and what next steps should be taken for each device. Finally the most important findings are highlighted and evaluated and future recommendations are made.

5.1. Problem analysis

Based on the analysis of the qualitative survey it can be identified that main challenges production line managers struggle with are lack of overview, unreliable data and the amount of complicated tools which can be confusing to use because of lack of instructions or training. The tools also work very differently from each other and need to be completely mastered separately before you are able to use them efficiently. At the same time there is an overflow of information and the lack of quality of the data that is actually needed. Often data records are either incomplete and/or inaccurate and they are found to be confusing and/or time consuming to evaluate. Too much of the data is tracked manually or with Excel sheets which are hard to find because of the confusing filing structure and often the same information is tracked in several places. A common complaint is that there is a lack of standardization of tools, data output and some of the interfaces.

There are distinct needs for having easily accessible complete and accurate data, decreased amount of evaluation tools needed for analysis and clarity on where you can find what information. Most tools are said to not to be self-explanatory which means that employees need to be supported better in understanding the tools they are using with for example integrated instructions which would not only help in figuring out what input goes where but also help navigating around the tool.

5.2. Requirements development

In this chapter the developed requirements are collected and evaluated on the basis of what elaboration is needed in the next steps of the RE process. A non-prioritized list of all developed requirements can be found in Table 4 with helping questions for evaluating how to make the requirement more actionable and relevant for the system development process. Besides specific questions addressed for each requirement, the full list of requirements should be reviewed for necessity, consistency, completeness and feasibility as part of requirements analysis.

Table 4. List of requirements for next generation Human-Machine-Interfaces

Requirement	**Further elaboration needed**
1. Interfaces must be logically and clearly organized for easy navigation and understandable visualization.	What is meant with easy navigation? What specifications are needed to make a visualization understandable?
2. Interfaces must be customizable for personal preferences.	What parts of the interfaces should be customizable? What should not? Under which conditions do you need to customize an interface?
3. Interfaces must provide an easily accessible overview of the most important KPIs.	Under which conditions?
4. Interfaces must provide a quick overview of the status of the production line.	Under what conditions? What constitutes as a quick overview?
5. Interfaces must display the data within a short time period.	How short period of time? What data should be displayed?
6. Interfaces must provide support in making using the system more understandable.	How should the support be given? How much support is needed?
7. Interfaces must be able accommodate to changes in the production (for example when a different product is produced in the production line).	What sort of changes? Under which conditions?
8. Interfaces must be able to display up-to-date, synchronized data.	How up-to-date should the data be? Under which conditions should the data be displayed?
9. Interfaces must have variable input options.	What should the input be? What should be displayed?

10. Visualizations of the interfaces must be uniform and standardized.	How many interfaces? All of them or some? What is the aim of standardization?
11. Interfaces must produce complete and up-to-date data.	Under which conditions? What data should be produced and how?
12. Interfaces must be simple to use.	What does it mean that an interface is simple to use?
13. Interfaces must store their data in a location from where they can be easily retrieved.	Under which conditions? Who should be able to retrieve the data?
14. Interfaces must produce data in a standardized format.	What should the standard be?
15. Interfaces must provide information on how an error has been fixed.	To whom? Under which conditions? What errors should be displayed?
16. Interfaces must produce high quality and reliable data.	Define high quality. Define reliable data.
17. Interfaces must do automatic evaluation of the produced data.	Evaluation of which data? What should be the output of the evaluation?
18. Interfaces must produce live data.	How "live" is live data? Who should be able to access it and from where?
19. Interfaces must show data on past failures.	To whom? Under which conditions?
20. Interfaces must enable displaying data in a variety of ways.	What ways? How many ways?
21. Interfaces must have online access.	Under which conditions?
22. Interfaces must enable remote access to data folders irrespective of the user's physical location.	Under which conditions?
23. Interfaces must enable remote access to evaluation tools irrespective of the user's physical location.	Under which conditions?
24. Interfaces must be able to load data in a short time period with minimal resources.	How short period of time? How little resources?
25. Interfaces must be easy to navigate.	What specifications are needed for easy navigation?
26. Interfaces must enable digital input.	Under which conditions? What sort of digital input? By whom?
27. Interfaces must have integrated KPI formulas.	Which KPIs? Which formulas?
28. Interfaces must make it possible to share photos and files.	Share photos to whom? How large files should be possible to share?

The next step for requirements development is to group connected requirements close to each other and analyze each requirement, divide them into sub-requirements and prioritize them in collaboration with the stakeholders. It is not expected that the developed system fulfills every single requirement which is why you need to prioritize them in order to fulfill the requirements that are most important to the customers, in this case the end users of the system that is being developed. You can also develop smaller solutions which cover different parts of the requirements list.

5.3. Priority list for future development projects

In this chapter the final conclusions are made on the results of the quantitative production floor survey in order to produce a priority list for future development projects involving smart devices. What could be seen is that smart phones and tablets are the most commonly known and used technologies among the surveyed people. Attitudes towards using smart phones or tablets in people’s work was viewed positively which was especially the case among 30-40-year-olds who demonstrated above average interests in integrating the devices to their work. Experience with smart glasses is rare and there was no age group which is significantly more proficient than the other. Young people are the most open minded about using smart glasses in their work even if they have no previous experience on using them. Experience with VR glasses is also rare and divides opinions on people’s willingness to integrate them into their work. Most skeptical people are people under 30 years old and people over 50 years old while people in between seem to be more open-minded about it. Using smart watches is more common among people under 30 years old within the surveyed population and they also favored the prospect of integrating them in their work more favorably than other age groups. This implies that there is a momentum of increasing user base of smart watches which could be taken into account in the long run product development strategy. This would have to be investigated further though since the sample size is not fully representative of the whole population on the production floors. People above 50 years old tend to be less experienced with technology and also more skeptical of it overall.

Based on these observations the following priority list of development projects is proposed:

1. Interface for tablets
2. Interface for smart phones
3. Interface for smart watches
4. Interface for smart glasses
5. Interface for VR Glasses

Tablet: This technology is very commonly known and not only was it the most positively viewed technology according to the statistics but it was specifically requested by a number of people when they were asked what they would want an ideal tool to do (Appendix 3). This serves as a great pilot project as there is a demand for it and it can be tested without interfering too much with the tools that are already in use, such as smart phones. The next step would be to take the proposed requirements list and evaluate it to prioritize the requirements and to think about the related system requirements. Stakeholder need to be involved in order to help with the prioritization and to also gather additional input in case some requirements are missing.

Smart phone: This is the most common technology people use on a daily basis and integrating is not likely to cause many problems. However, it would be wise to first test out features developed on the tablet interface and benchmark the working features from there since the working principle of a smart phone interface and tablet interface is generally similar. Also, since smart phones are already in use by some employees it could be confusing to test out new interface when you are used to the way the smart phone in use currently works, which could cause problems in their work. It is better to keep the smart phone interfaces as they are until some critical concepts have been proven to work on a tablet.

Smart watches: Out of the less known technologies smart watches were most positively viewed. It is also that there is indication that smart watches are more common among younger generations so this could be a critical technology in the future if the potential is used fully. It has to be evaluated though what exactly smart watches would be used for and what are the potential applications before starting the HMI development process for it.

Smart glasses: This is the technology that many people know of, but only very few have any experience in using it. Although potential applications are well known, what could hinder the adoption of smart glasses is the fact that people are not familiar in using it. What could be a good practice in order to speed up the diffusion of this technology is organize opportunities where intended end users get to experiment and play with them in order to get an idea on how they work and what they could be used for. Young people are most open minded about this technology and therefore they can serve as a good target group for experimentation.

VR Glasses: VR glasses are also quite unknown and people were most skeptical about using them in their work. There needs to be an evaluation of what applications they could have so people could be more easily convinced to adopt them. For now integrating VR glasses into the work flow is in the distant future.

5.4. Important findings

There seems to be a lot of systematic problems that need to be tackled before any new tool is introduced to the work flow. First things that should be sorted out is standardizing data output, replacing hand written information boards and countless Excel used for tracking with a digital platform that collects the same information and finding ways of centralizing the databases to make looking for information less confusing.

Secondly what is interesting is that empirical research shows that when people have had the chance to experiment with technology at least once, that makes them twice as likely to be willing to integrate the technology into their work. This implies that efforts should be made to give people opportunities to experiment with the potential future tools before they are actually introduced in order to mitigate change resistance among intended end users.

Thirdly, the biggest obstacle that production line managers are facing is the time they consume switching between multiple evaluation tools that are complicated and confusing to use in order to get an overview of the KPIs they are tracking. On top of that there is lack of training in using them which further deepens the confusion in using them. In short term more training for using the most common evaluation tools should be made available to those who would want to supplement their knowledge on the tools.

5.5. Evaluation of findings

The conclusion on the positive correlation of past experience and openness towards integrating the technology in question was based on the analysis done on a controlled data set with random input. With 814 data points the result can be said to be reliable. Unfortunately there was no time for researching literature to verify the result and to gain insights on the reasons behind this psychological phenomena.

What needs to be acknowledged is that majority of the participants of the qualitative survey are operators and therefore the results from the data may be skewed more towards the point of view of operators. It might be interesting to do a similar survey with only managers to see if their point of view on integrating existing smart devices into their work is significantly different from the survey that was conducted as part of this thesis.

5.6. Recommendations

For next steps it would be recommendable to analyze and prioritize the requirements list produced in this thesis to make more sense of which requirements have higher priority and should be implemented first when developing a new system. It is important to do rapid prototyping in order to fail early so you can learn from mistakes faster and rebuild a better product that can fulfill more user requirements in a shorter time period. You can also use Joint Application Development technique explained in chapter “2.2.2. Requirements analysis”. In order to ensure faster diffusion of new technology the management should identify innovators and early adopters, or opinion leaders, in the community who serve as key players in making technology introduction smoother. Additionally in order to mitigate change resistance in technology introduction people should have the opportunity to experiment with the future devices before they are officially introduced into the work flow.

5.7. Future research

Further investigation should be done on the following topics:

1. Verify the research results of the positive correlation between past experience in using a technology and one’s attitude towards it. Check to see if similar results have been produced in other research papers in the context of other companies and industries.
2. Prioritize and validate the requirements list with the stakeholders to gain input about their priorities and supplement the requirements list with missing requirements by using for example focus groups.
3. Evaluate the existing information flow channels and database structures to see where are the parts of the system that have the highest importance and urgency to be improved.

6 CONCLUSIONS

In this paper a combination of Requirements Engineering and Design Thinking, more specifically requirements elicitation, Research and early stage of Ideation parts of the respective techniques, was used to discover explicit and underlying needs of production line managers in order to gain understanding on what they would want a future Human-Machine-Interface to do. Based on these needs a list of requirements was produced. Additionally an investigation was done on production floor employees' effort expectancy and performance expectancy on various smart devices that are available today in order to narrow down which technologies would be most likely to be adopted successfully into the production floor workflow. Based on the analysis of effort expectancy and performance expectancy a priority list of potential future HMI development projects was created.

As a part of the qualitative analysis customer profiles, or personas, were created for Focus Factory industrial engineers, shift leaders and system administrators. The purpose of this was to gain an understanding the tasks and responsibilities of each position, what are the methods they use and what are the respective collective view points on what works and what does not in current environment. Common issues found across different job functions were lack of quality data, confusing tools and data storage structures, and struggles with having a complete overview of important information, which can be time-consuming when you need to switch around between several tools while searching for information.

In the quantitative survey it was discovered that there is awareness of Industry 4.0 as a concept among the survey participant pool and that the opinions on it are rather divided. A more detailed investigation would be needed to understand the reasoning behind each individuals attitudes towards the current topic which was not possible to do with the chosen methodology. The main conclusions were that a lot of people have solid experience in using smart phones and tablets which would make it easy to integrate them in the workflow if they were introduced by the management, given that a functioning HMI has been developed for them. Smart watches are more common among young people and it should be investigated if this is representative of a larger population. Experience with smart glasses and VR glasses is rare and in order to speed up their diffusion into the workflow, efforts need to be made to give workers opportunities to experiment with them before serious discussions about implementing them to the workflow can be started. The main discovery of the quantitative analysis is the positive correlation between experience in using a device and the openness towards the idea of integrating it to one’s work. There is a significant positive difference in the attitude between having experimented with a technology at least one time as opposed to being aware of it but having no experience in using it.

Research question 1: What challenges and needs do different production line managers have with digital tools in Continental Regensburg plant?

Most common challenges are related to lack of access to complete and accurate data that is needed for evaluation and analysis. On top of that there are too many complicated evaluation tools that work independently from each other and need to be studied carefully before it is possible to use them efficiently, and there is a lack of support in learning to use them. It is not always clear where you can find specific Key Performance Indicator and having a complete overview of most important information is very time-consuming as you need to switch between multiple tools at a time. A lot of times large data files take a long time to load, and it is not always clear from which location you need to search specific information.

There is a need to have less confusing filing structures, decreased amount of necessary evaluation tools and more support in using existing tools. People should be enabled to access reliable information irrespective of their location in the production plant. There is also a need for tools that would replace the large amount Excel data sheets and manually tracked information, which can be inaccurate and out-of-date when not maintained well enough.

Research question 2: Which portable and wearable devices can be introduced into the production floor workflow in Continental Regensburg plant with the least amount of change resistance and effort required from workers to learn to use the device?

Based on the quantitative analysis it is recommended to start with tablets, then smart phones and later on smart watches. These are the most commonly known technologies and are mostly seen in a positive light when it is suggested to people to integrate them into their work. While smart phones and tablets are very commonly used already today, smart watches hold potential to be more easily adoptable in the future as smart watches are viewed more positively among younger generation of people compared to older ones. Smart glasses and VR glasses are viewed most skeptically which is why efforts need to be made to familiarize people with them and in that way speed up the adoption process.

Research question 3: How to ensure a successful design and implementation of new digital systems in the production lines?

You need identify the innovators and early adopters in the employee community and involve them in the product development process. Not only they most likely to experiment with a relatively new technology but they serve as opinion leaders and ambassadors once a finished product is introduced. In order to mitigate change resistance and to increase the likelihood of people being willing to integrate new technology people should be given opportunities to experiment with the technology before the official introduction.

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APPENDICES

APPENDIX 1

Qualitative management survey in German and English

Über sich selbst

Um Ihre Rolle in der Organisation zu verstehen, möchten wir Sie bitten, folgende Fragen zu beantworten

1. Was ist Ihre Rolle oder Funktion?

(Bitte wählen Sie Ihre Antwort aus, indem Sie auf <u>*ein Kästchen*</u> ☐/☒ *klicken oder schreiben Sie in "Andere:")*

☐ Schichtleiter

☐ Linienleiter

☐ Systembetreuer

☐ FF IE

☐ Andere:

2. Beschreiben Sie Ihren Job in eigenen Worten. Was sind Ihre Aufgaben und Verantwortlichkeiten?

3. Welchen Performance Indicators (KPIs) folgen Sie bei Ihrer Arbeit an den Produktionslinien?

Ihre Methoden

Um Ihre Arbeitsweise und die Art und Weise, wie Sie mit den Maschinen umgehen, zu verstehen, möchten wir Ihnen die folgenden Fragen stellen. Mit diesem Fragenkomplex wollen wir herausfinden, welche Features und Funktionen wir bei der Entwicklung der nächsten Generation der Mensch-Maschine-Schnittstellen beibehalten oder integrieren sollten und welche nicht.

4a. Wie sammeln Sie die Informationen, die für Ihre Arbeit relevant sind? Haben Sie spezielle Methoden oder Werkzeuge, die Sie verwenden?

4b. Was gefällt Ihnen an den Methoden, die Sie derzeit anwenden? Warum?

4c. Was gefällt Ihnen daran nicht? Warum?

5a. Beschreiben Sie einige der Mensch-Maschine-Schnittstellen, mit denen Sie in Ihrer Arbeit interagieren.

5b. Was gefällt Ihnen daran? Warum?

5c. Was gefällt Ihnen daran nicht? Warum?

5d. Können Sie weitere Beispiele für Mensch-Maschine-Schnittstellen nennen, von denen Sie wissen, dass sie in Continental verwendet werden, aber Sie selbst diese nicht verwenden?

6. Was sind die häufigsten Hindernisse, mit denen Sie beim Sammeln von Informationen für Ihre Arbeit konfrontiert sind?

7a. Ein neues Werkzeug wird eingeführt, um Ihnen die Arbeit zu erleichtern. Was würde es idealerweise tun? Welche Funktionen sollte es haben?

7b. Wie würde dies dazu beitragen, Ihre tägliche Arbeit zu verbessern?

Ihre Kollegen

Wir möchten mehr über Ihre Arbeitsumgebung erfahren und darüber, wie Sie mit Menschen in Ihrer Umgebung umgehen.
Anmerkung: Um die Anonymität zu gewährleisten, verwenden Sie bitte keine Namen in Ihren Antworten. Wenn Sie sich auf Ihre Vorgesetzten bzw. Personen auf der gleichen Ebene bzw. Teammitglieder beziehen, beschreiben sie diese nur mit ihren Rollen- oder Jobfunktionen.

8a. Wer sind die Menschen, mit denen Sie am häufigsten in Ihrer Arbeit interagieren?

8b. In welchen Situationen interagieren Sie normalerweise mit den genannten Personen?

8c. Nach welchen KPIs richten sich ihre Kollegen in der Regel bei ihrer Arbeit?

About yourself

In order to understand your role in the organization we would like you to answer the following questions

1. What is your role or job function?

(Please choose your answer by clicking on *<u>one box</u>* ☐/☒ *or write in "Other:")*

☐ Shift Leader

☐ Line Leader

☐ Technician

☐ FF IE

☐ Other:

2. Describe your job in your own words. What are your tasks and responsibilities?

3. What are the Key Performance Indicators (KPIs) you follow in your work at the production lines?

Your methods

In order to understand your working methods and how you interact with the machines we would like to ask you the following questions. With this set of questions we want to find out which features and functions we should keep or integrate, and which features we should not keep, when designing the next generation Human-Machine-Interface(s).

4a. How do you collect the information that is relevant to your work? Do you have any specific methods or tools that you use?

4b. What do you like about the methods that you are currently using? Why?

4c. What do you not like about them? Why?

5a. Describe some of the Human-Machine-Interfaces that you interact with in your work.

5b. What do you like about them? Why?

5c. What do you not like about them? Why?

5d. Can you name other examples of Human-Machine-Interfaces that you know are used in Continental but you do not use yourself?

6. What are the most common obstacles you face when gathering information for your work?

7a. A new tool is introduced to make your work easier. What would it ideally do? What functions would it have?

7b. How would this help to improve your daily work?

Your colleagues

We want to learn about your working environment and how you interact with people around you. Remark: To ensure anonymity please do not use names in your answers. When you are referring to your superiors, people on the same level as you or your team members, specify by their roles or job functions.

8a. Who are the people you interact with most often in your work?

8b. In what situations do you usually interact with the mentioned people?

8c. What KPIs do your colleagues usually follow in their work?

APPENDIX 2

Quantitative production floor survey in German and English

Dieser Fragebogen wurde im Rahmen einer Masterarbeit erstellt. Die befragung wird bei Continental Regensburg in der FF2 & FF3 durchgeführt. Mit diesem Fragebogen soll untersucht werden, wie vertraut die Mitarbeiter der FF2 & FF3 bei Continental Regensburg mit moderner Technik sind und wie ihre Einstellung zu diesem Thema ist. Der Fragebogen ist völlig anonym und wird nicht für die Mitarbeiterbeurteilung verwendet. Bitte wählen Sie bei jeder Frage die Option, die am ehesten zutrifft. Das Ausfüllen des Fragebogens sollte nicht länger als 2-5 Minuten dauern.

Wie alt sind Sie?

- ☐ 0-20 Jahre
- ☐ 21-30 Jahre
- ☐ 31-40 Jahre
- ☐ 41-50 Jahre
- ☐ 51-60 Jahre
- ☐ 61-70 Jahre
- ☐ 71+ Jahre

Ich arbeite in meiner Position seit:

- ☐ Weniger als 3 Monate
- ☐ 3-6 Monate
- ☐ 6-12 Monate
- ☐ 1-2 Jahre
- ☐ 2-4 Jahre
- ☐ Mehr als 5 Jahre

Haben Sie schon einmal vom Konzept der intelligenten Fabriken oder von Industrie 4.0 gehört?

- ☐ Ich habe noch nie davon gehört.
- ☐ Ich habe davon gehört und bin skeptisch.
- ☐ Ich habe davon gehört und habe eine neutrale Meinung dazu.
- ☐ Ich habe davon gehört und habe eine positive Meinung dazu.
- ☐ Ich habe davon gehört und würde gerne aktiv daran teilnehmen.

Wie vertraut sind Sie mit den folgenden Technologien oder Geräten:

	Ich habe noch nie davon gehört	Ich habe davon gehört, aber ich habe keine Erfahrung mit diesem Gerät	Ich habe davon gehört und mindestens einmal mit dem Gerät experimentiert	Ich habe mäßige Erfahrung im Umgang mit diesem Gerät	Ich benutze oder benutzte es regelmäßig
Smartphone					
Tablet					
Intelligente Brillen					
Virtual Reality-Brille					
Smarte Uhren					

Ich bin bereit, folgende Technologien oder Geräte in meine Arbeit zu integrieren:

	Ich sehe keinen Grund, dieses Gerät in meine Arbeit zu integrieren	Ich glaube nicht, dass diese Technologie bereit ist, in meiner Arbeit eingesetzt zu werden	Ich würde mich nicht wohl fühlen oder ich bräuchte eine Schulung, um dieses Gerät in meine Arbeit zu integrieren	Wenn ich die Option hätte, würde ich diese Technologie sofort in meine Arbeit integrieren	Ich benutze dieses Gerät bereits in meiner Arbeit
Smartphone					
Tablet					
Intelligente Brillen					
Virtual Reality-Brille					
Smarte Uhren					

Wenn man diese Technologien oder Geräte in die Arbeit einführen würde, denke ich, dass die allgemeine Meinung meiner Mitarbeiter/Kollegen wie folgt lauten würde …

	Sehr negative	Eher negative	Neutrale oder gemischte	Eher positive	Sehr positive
Smartphone					
Tablet					
Intelligente Brillen					
Virtual Reality-Brille					
Smarte Uhren					

This questionnaire has been created as part of a master thesis that is being completed in Continental Regensburg FF2 & FF3. The purpose of this questionnaire is to investigate how familiar employees in Continental Regensburg FF2 & FF3 are with modern technology and their attitudes towards them. The questionnaire is completely anonymous and will not be used for any employee evaluation purposes. For each question we kindly ask you to choose the option that is closest to your thinking. Filling the questionnaire should not take you longer than 2-5 minutes.

Your age:

- ☐ 0-20 years old
- ☐ 21-30 years old
- ☐ 31-40 years old
- ☐ 41-50 years old
- ☐ 51-60 years old
- ☐ 61-70 years old
- ☐ 71+ years old

I have worked in my position for:

- ☐ Less than 3 months
- ☐ 3-6 months
- ☐ 6-12 months
- ☐ 1-2 years
- ☐ 2-4 years
- ☐ More than 5 years

Have you ever heard of the concept of smart factories or Industry 4.0?

- ☐ I have never heard of this
- ☐ I have heard of it and I feel skeptical about it
- ☐ I have heard of it and have a neutral opinion on it
- ☐ I have heard of it and have a positive view on it
- ☐ I have heard of it and I would take an active role in it

How familiar are you with the following technologies or devices:

	I have never heard of this	I have heard of it, but do not have experience in using this device	I have heard of it and have experimented with the device at least once	I have moderate experience in using this device	I either use or have used one on a regular basis
Smart phone					
Tablet					
Smart glasses					
Virtual Reality glasses					
Smart watches					

I would be willing to integrate the following technologies or devices to my work:

	I do not see any reason in integrating this device to my work	I do not think that this technology is ready to be used in my work	I would not feel comfortable or I would need some training to integrate this device to my work	Given the option, I would integrate this technology to my work right away	I already use this device in my work
Smart phone					
Tablet					
Smart glasses					
Virtual Reality glasses					
Smart watches					

If these technologies or devices were introduced to the work, I think that the general opinion of my co-workers would be…

	Very negative	Slightly negative	Neutral or mixed	Slightly positive	Very positive
Smart phone					
Tablet					
Smart glasses					
Virtual Reality glasses					
Smart watches					

APPENDIX 3

Translated answers for ideas for an ideal imaginary tool and analyzed underlying needs of the respondents

Requested feature(s) or function(s)	**Underlying user need(s)**
Clear presentation of all KPIs via one tool	Clear overview of KPIs, decreased amount of evaluation tools needed
Display live data (not older than one day) of the most important KPIs. Evaluate or derive the data from this tool for evaluations	Up-to-date, live data
Tracking the KPIs I provide is reliable and largely independent of human input. The best way to evaluate these KPIs is to use a tool.	Reliable and automatic data output
Provide reliable and reproducible data that can be evaluated sensibly	Reliable and easy to understand data
Provide data for evaluation	Data
An overview without handwritten entries, only with calculator/laptop…	Clear overview, digital input
Fast and easy to use	High performance tool, ease of use
Intuitive menu navigation	Easy to navigate tool
It should be clear and easy to use. Ideally self-explanatory. Data should be displayed in different ways (eg. graphically)	Ease of use, adequate support in using the system, diversity in ways of displaying data
Scrap, OEE, FPY to one click per line	Clear overview of KPIs
Tool should be compatible with most systems that it can be directly used at plant operations, as well as support access from the office. Ideally, access via home office should be possible in order to be able to support emergencies on weekends or to evaluate data in case of problems. Tool should be lean and require little resources, so that it can be used everywhere and run without long waiting times.	Compatibility, remote access, home office access, live data, lean software, mobility with data
Internet-capable, portable, should be able to access all folders, furthermore more tools and apps should be introduced, which replace many Excel lists and work without bugs, eg. app which shows to-dos from all meeting protocols	Access to internet, mobility with data, access to data folders, replacement for Excel, to-do-list from meetings

Requested feature(s) or function(s)	**Underlying user need(s)**
Display of running processes and plants, standing plants and processes. Display of the last failures (number, error, type). Optical processing monitor (video surveillance) to understand errors. The integration of existing production plants and processes.	Live data, data on past failures, video monitoring
Connection of the various individual tools; Documentation for Deviation Management/Regensburg should be changed from Excel to a useful tool with the functions for hourly quantity / number of analysis parts.	Interconnected with other tools, replacement for Excel, integrated KPI calculations
Many interfaces unite with each other, eg. production information, personnel planning, real time KPIs, SAP functions. All data also available on mobile devices	Decreased amount of evaluation tools,
A tablet with WLAN and SAP access	Mobility with data, internet access, non-location dependent access to tools
Eg. the function of a tablet with WIFI. So that you get all the information directly at the plant and do not have to visit a PC [to retrieve information]. It should be able to display all relevant data and information. Spare parts could also be booked directly on site.	Mobility with data, access to internet, clear overview of KPIs, non-location dependent access to tools
A tablet that has all the necessary apps on the start page and therefore all the necessary key figures can be called up and, if necessary, changed. In those apps, all necessary data from the respective systems and processes should always be up-to-date. In this case it will be important that a lot of data is played back by the system independently via a common language. (currently unthinkable due to the multitude of different plant manufacturers and missing interfaces)	Mobility with data, non-location dependent access to tools, clear overview of KPIs, non-location dependent possibility to write input, live data

Requested feature(s) or function(s)	Underlying user need(s)
Minimise work time and effort to achieve the desired results. Not too much, because then the effort to serve it will be too great again	Increased efficiency
Ideally, preventive measures should be taken to build simple systems that are easy to reach	Ease of use, ease of access
It is freely editable (choose what is written where and how) Functions depend on the individual cases	Customization
For faster diagnosis of escalations, there should be a tool for creating and sending screen printouts of production computers in case of errors. The subject is not as trivial as it seems. For test-PCs, for example, the [Internet] Explorer is deactivated. Using private mobile phones is of course forbidden.	Photo / screen printout sharing with colleagues
It should have an overview of its functions with the possibility to look at how to use these functions of the tool and what you have to do (for example) for inputs.	Adequate support for using a system
Try to get to know the tool. It should be easy to use and self-explanatory. The tool should be tested with the user beforehand. An overview of all training courses.	Ease of use, adequate support for using a system, clear overview on available training courses
When a new tool comes along, others have to be replaced first. There can't be too many. It should be easy to handle and work fast.	Decreased amount of evaluation tools, ease of use, high performance tool
Evaluate the logfiles automatically. You only need to enter the time period. The parameters I want to have evaluated can be defined by myself in the tool. It should be self-explained.	Automatic data evaluation, ease of access to data, customizable, adequate support for using the system
Enable communication among colleagues by using smartphones and appropriate (company internal) communication app	Ease of communication
Running [tool] with high quality data at all production facilities	High quality data