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Digitalization in the manufacturing sector: Current state, impact on performance and determinants of adoption

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Abstract

The master thesis, “Digitalization in the manufacturing sector: Current state, impact on performance and determinants of adoption”, offers the reader deep insights into the topics digitalization and the development towards Industry 4.0: in particular this thesis focuses on the manufacturing sector. The practical part of this thesis deals with the topics, Industry 4.0., digitalization, digital intensity within the manufacturing sector and with the four clusters of disruptive technologies. In addition, the most relevant digital technologies are presented in detail to the reader within the four clusters of digital technologies. First, a general overview is given for every analyzed digital technology, followed by an example of implementation, then the benefits as well as the costs are discussed and finally the risk related to each digital technology is analyzed. In addition, with the aim of answering the four research questions, the practical part of this thesis is built on self-conducted interviews with representatives from manufacturing companies. These interviews are then analyzed with the support of the self-developed maturity model “Digitalization towards Industry 4.0”. The application of this model reveals at which level of digital maturity the interviewed manufacturing companies currently are. The practical part offers further promising findings about the topics digitalization and Industry 4.0.

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"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change."

Charles Darwin (1809-1882)

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Abbreviations

3D:	Three-dimensional
AI:	Artificial Intelligence
AIDC:	Automatic Identification and Data Capture
AR:	Augmented Reality
BI:	Business Intelligence
BMWi:	Bundesministerium für Wirtschaft und Energie
CPS:	Cyber physic systems
CPU:	Central processing unit
DARPA:	Defense Advanced Research Projects Agency
DSRC:	Dedicated Short Range Communication
EBITDA:	Earnings before interest, taxes, depreciation and amortization
EDI:	Electronic data interchange
EMS:	Enterprise management system
ERP:	Enterprise Resource Planning
et al.:	et alia
HD:	High-definition
HMI:	Human Machine Interaction
IBM:	International Business Machines Corporation
IaaS:	Infrastructure as a service
IoT:	Internet of Things
IT:	Information Technology
ITS:	Intelligent Transportation Systems
M2M:	Machine to machine
MES:	Manufacturing execution System
MIT:	Massachusetts Institute of Technology
NYSE:	New York Stock Exchange
PaaS:	Platform as a Service
PwC:	PricewaterhouseCoopers
P&G:	Proctor and Gamble

RFID:	Radio-frequency identification
R&D:	Research and development
SaaS:	Software as a service
V2I:	Vehicle-to-infrastructure
V2V:	Vehicle-to-vehicle
VR:	Virtual Reality

Chapter 1

1. Introduction

With the completion of the development and the construction of the first fully automatic programmable digital computer, the Z3 in 1941, by Konrad Zuse (Rojas, 1997) and the invention of the Internet, the structure of which was developed out of a stack of technologies and standards in the last two decades of the 20th century, the foundations for the digitalization was laid (Oppitz and Tomsu, 2017). Nevertheless, it took society around half a century after the invention of Zuse, until it was widely recognized how significant these technological developments are and which opportunities they offer (Cachelin, 2012).

Nowadays the terminology digitalization is omnipresent and terms like Industry 4.0, Big Data, Internet of Things, Artificial Intelligence, Augmented Reality and Cyber Physic Systems are increasingly used in business, in the media and in politics. Technologies which were several years ago unthinkable and regarded as pure science fiction are becoming reality now and in some years, they are expected to be an ordinary part of our daily life. For instance, the daily newspaper in the morning on a smartphone or tablet, listening to the newest songs via an on-demand music streaming service on the way to work, having a video conference with colleagues from all around the world, using a messenger to share a newly made picture with friends and relatives, trading stocks on the NYSE on the way to the gym or watching the newest episode of your favorite TV show online. These are all fields in which the digitalization of products and services changed existing industries or created completely new ones.

Moreover, digitalization even made former well-established companies and products obsolete, were at the same time new companies emerged on the market. Examples for these developments are: Nokia and their failed approaches towards the smartphone market, the Eastman Kodak Company and their missing of the market for digital photography and Spotify Technology’s disruptive business model and the music industry (Bouwman et al., 2014; Lucas and Goh, 2009; Wlömert and Papies, 2016). Consequently, digitalization is creating a demand for change and for the transition of whole business models, as digitalization and the related disruptive technologies are not only changing our daily lives, they are also changing whole industries from scratch. Hence, digitalization is increasingly becoming a fundamental requirement for companies and organizations in order to survive on the market and to beat the competition (Oppitz and Tomsu, 2017).

As far as the manufacturing industry is concerned, this sector has not yet been transformed in a fundamental way like other ones (Ebner et al., 2013). On the one hand, 58 percent of the companies within the manufacturing sector are expecting new competitors on the market due to Industry 4.0 and the related developments. And even more companies, four out of five are expecting Industry 4.0 to affect their business model. On the other hand, only 48 percent of the manufacturing companies have the feeling that they are well equipped for Industry 4.0, the process of digitalization and the related challenges. However, digitalization is expected to affect sooner or later also the manufacturing sector in an enormous way (McKinsey Digital, 2015). Companies within the manufacturing sector should be aware of these developments, as in terms of digital intensity, companies within that sector are contemporarily relatively slow in adopting digital technologies compared to companies from other industries like retail, banking and telecommunication. Nevertheless, also in the manufacturing sector digitalization is likely to be the key in order to upgrade existing or to develop new products and services that have the potential to outperform the competition in the future (Ebner et al., 2013).

The digitalization of the manufacturing sector means that the central controlled and automated production known as Industry 3.0 is transformed into a self-controlled and flexible production known as Industry 4.0 (Leyh et al., 2016). This transformation of the manufacturing sector towards Industry 4.0 is driven by four clusters of disruptive technologies: Data and connectivity, analytics and intelligence, human machine interaction (HMI) and digital to physical conversion (McKinsey Digital, 2015). The named clusters and the technologies located within these clusters will be analyzed in detail in this thesis, as the process of digitalization is based on the acceptance and implementation of new digital technologies (Oppitz and Tomsu, 2017).

All these developments and changes are raising a couple of questions, what does digitalization mean to a single manufacturing company and to the whole sector, to which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies, what is the current state of digitalization among manufacturing companies, what impact digitalization has on the performance of companies within the manufacturing sector, what determines the adoption of digital technologies of companies within this sector, which technologies can drive the change of a manufacturing company towards Industry 4.0, how can these technologies change the production process, how high are the costs of implementation, which risks are companies facing when they implement these technologies and how can digital technologies help manufacturing companies beat the competition? These are the questions that will be discussed.

The aims of this thesis are to outline to what extent manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies, the current state of digitalization in the manufacturing sector, the impact of digitalization on the performance of companies within that sector and the determinants of adoption for digital technologies within the manufacturing sector.

1.1. Research Questions and objectives of the thesis

Based on the aims of this thesis and the questions raised in the previous introduction, the following four research questions are offered:

"To which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies?"

"How can digitalization help manufacturing companies in the field of manufacturing operations, supply chain and service maintenance?"

"What is the current level of digitalization among manufacturing companies?"

"What are the determinants of adoption of digital technologies in the manufacturing sector?"

The primary aims of this thesis are to find out which state of digitalization the manufacturing sector is currently in, what impact digitalization has on the performance of a company and what are the determinants of adoption for digitalization and the related technologies. The secondary aim of this thesis is to investigate a still reasonably unexplored and new research topic, in order to get up to date with the latest trends in the manufacturing sector concerning the topic of digitalization.

Concerning the published literature on digitalization, the available literature and the related topics are still developing as the process of digitalization is just getting started. Furthermore, there is a relatively large gap between theory and practice in that field. Detailed practical examples for the implementation of up to date digital technologies are relatively rare. The existing literature shows a lack of how manufacturing companies actually implement digital technologies and what the concrete effects of implementation of the single digital technology on the performance of the company are.

In order to reach the challenges that were named above, theoretical and practical findings are compared and analyzed in this thesis. This thesis itself consists of primary as well as secondary data. Secondary data is mainly used to build up the theoretical framework of the thesis. Whereas, primary data is used to highlight the results of the conducted expert interviews with representatives of manufacturing companies and consequently to answer the four research questions of this thesis.

The practical part of this thesis is based on expert interviews. These interviews are conducted with representatives of manufacturing companies. The aim of these interviews is to understand how manufacturing companies approach the process of digitalization towards Industry 4.0, if and how these companies collaborate with external partners concerning the process of digitalization, to which extent manufacturing companies have already implemented digital technologies and what the determinants of the adoption of these digital technologies in the manufacturing sector are.

Digitalization in the manufacturing sector: Current state, impact on performance and determinants of adoption, a master thesis to discover to which extent companies in the manufacturing sector have implemented digital technologies. Therefore, the maturity model "Digitalization towards Industry 4.0" has been developed. This maturity model is developed to find out how advanced companies from the manufacturing sector are when it comes to the process of digitalization and the development towards Industry 4.0. Moreover, the conducted expert interviews with representatives of manufacturing companies should find out why some companies implemented specific solutions like 3D-printing and CPS and why other companies still avoid them.

1.2. Outline of the thesis

In order to find the correct answers to the presented research questions and to increase the understanding of digitalization in the manufacturing sector this master thesis is structured into five main chapters. Chapter 1 contains a brief introduction into the topic of the thesis. Chapter 2 deals with the practical part of the thesis. To make the reader familiar with the scientific field and the topic of the thesis, chapter 2.1. presents an overview about the concept of Industry 4.0, a brief description of the previous three industrial revolutions and an answer to the question of, if Industry 4.0 is an industrial revolution in the dimension of the previous three industrial revolutions. In chapter 2.2. the terminology digitalization is presented in detail to the reader and the economic and social impacts of digitalization are discussed. In chapter 2.3. the current digital intensity of the manufacturing sector is analyzed and presented to the reader. Chapter 2.4. deals with the four clusters of disruptive technologies: Data and connectivity, analytics and intelligence, human machine interaction and digital to physical conversion. Each of these four clusters will be discussed in their own subtopic. Within these subtopics the most promising disruptive digital technologies that have the potential of transforming the manufacturing sector are going to be presented and analyzed in detail. Examples for key technologies are the Internet of Things, Artificial Intelligence, Augmented Reality and Cyber Physic Systems. Chapter 3 describes the Methodology as well as the research objectives of the thesis. Chapter 3.1. presents the Methodology and in four subtopics the scientific contribution, the research approach, the research questions and the research design of the thesis. In chapter 3.2. the maturity model "Digitalization towards Industry 4.0" is developed and presented in detail to the reader. In chapter 4 of this thesis the results of the conducted interviews with representatives of manufacturing companies are presented and discussed. Chapter 4.1. deals therefore with the results of the conducted interviews. In chapter 4.2. the results of conducted interviews are analyzed and interpreted. Consequently, chapter 4.2. also reveals the answers to the four developed research questions. Chapter 4.3. presents the limitations of the thesis and based on these limitations suggestions for further research are given. Finally, in chapter 5 the conclusion of the thesis is given to the reader. In this conclusion the most relevant findings are shown and based on these findings recommendations are made.

Chapter 2

2. Digitalization and Industry 4.0

2.1. Industry 4.0

Industry 4.0, also known as the fourth industrial revolution, is a terminology that is increasingly being used in Germany. In Austria and Switzerland, the term Industry 4.0 is also gaining more and more popularity (Barthelmäs et al., 2017). The fact that the term Industry 4.0 is mainly used in Germany and German speaking countries is caused by the circumstance that originally the term has its roots in Germany. The German government, several companies, universities and a number of other organizations introduced "Industrie 4.0" as the name of the high-tech strategy of the German government. This high-tech strategy was supposed to be a project for the future of the German industry. The aim of the strategy "Industrie 4.0" is to develop the German manufacturing sector and to increase its competitiveness on the global market (BMWi, 2016; Kaufmann, 2015).

Industry 4.0 is often used in the field of business, in university lecturers and in scientific studies. In all these fields, Industry 4.0 and the different approaches of it are temporally heavily debated. But what does Industry 4.0 exactly mean and which fields do the concept Industry 4.0 include and which not? Generally, the term Industry 4.0 leaves a lot of room for discussions as there is no universally valid definition available for it yet and what Industry 4.0 exactly means for the economy and for society in general (Barthelmäs et al., 2017). Most of the time, Industry 4.0 is used as an umbrella term for digital technologies which are capable of being implemented in the manufacturing sector and have the potential of increasing the performance of manufacturing companies in the future. Hence, the terminology Industry 4.0 describes the trend towards an on-going digitalization of the manufacturing sector (Kaufmann, 2015). Additionally, the fourth industrial revolution stands for an intensified digitalization of products, systems and their connection with another. In this process the physical world is connected to the virtual world. Thereby a high focus is diverted to the increase of automatization, flexibility and individualization of the production and the underlying processes. The consulting corporation McKinsey & Company developed a reasonably fitting definition for the term Industry 4.0 and defines it as "digitalization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical-systems and analysis of all relevant data” (McKinsey Digital, 2015). Consequently, the concept of Industry 4.0 describes the stage after a central controlled production, also known as Industry 3.0, is digitalized and transformed into a self-controlled and flexible production. In this self-controlled and flexible production all products, systems and steps in the whole process are digitalized and interconnected. Therefore, information is shared vertically and horizontally all over the supply chain (Leyh et al., 2016).

Furthermore, the term automation is not equivalent to the terminology Industry 4.0 (Roland Berger GmbH, 2016). Automation is a key aspect of Industry 3.0 (V. P. Andelfinger, 2017; Leyh et al., 2016). Moreover, the automation of manufacturing processes is only getting more efficient if more capital is bound into these processes. A more efficient way of using capital is achieved through the use of Industry 4.0 and the related digital technological solutions (Roland Berger GmbH, 2016). Industry 4.0 and these technologies have the capability to increase the competitiveness of a company significantly. An indicator of this high level of competitiveness are the high flexibility standards of the manufacturing sector with the development towards the lot size of one and mass customization. In a future world where Industry 4.0 is reality, the components will find their own way to the next step in the production process without any human interference. Machines will know by themselves when they are going to fall apart, and the whole production process will automatically adjust itself due to this future event (BMWi, 2016; Hänisch, 2017; Kaufmann, 2015).

Industry 4.0 is driven by a set of four clusters of disruptive technologies. The first cluster is Data and connectivity. This field includes for instance the Internet of Things (IoT), Big Data and cloud computing. The second cluster is Analytics and Intelligence. Examples for this field is Artificial Intelligence (AI). The third cluster is human machine interaction (HMI). Augmented Reality (AR) and Virtual Reality (VR) could be examples for human machine interaction. The fourth cluster of disruptive technologies is digital to physical conversion. Examples for this cluster are Cyber Physical Systems (CPS) and 3D-printing. In this thesis the four clusters of disruptive technologies and all relevant technologies which are part of these clusters will be analyzed and discussed in detail (McKinsey Digital, 2015).

The potential of Industry 4.0 is enormous, as it is expected that companies all over the world will invest by the year 2020 over 900 billion US-Dollars per year into technologies which are related to Industry 4.0 (Geissbauer et al., 2016). Moreover, through the implementation of digital technologies which are related to Industry 4.0 the capital efficiency in Western Europe could increase from 18 percent in the year 2016 up to 28 percent in the year 2035. Consequently, this growth in capital efficiency would lead to higher profits and less bounded capital. This development could create an additional value added of 420 billion Euro until the year 2035 (Roland Berger GmbH, 2016). Furthermore, experts are expecting Industry 4.0 and the related technologies to increase the revenues of manufacturing companies by 23 percent and their productivity by 26 percent (McKinsey Digital, 2015). Also, an incrementation in yield in the manufacturing sector is possible; this could be achieved through the implementation of technologies that are related to Industry 4.0. The consulting company Roland Berger GmbH illustrates in an example about a supplier in the automotive industry how the yield on capital used can be increased from 25% to 40%. This growth was achieved through upgrading the manufacturing process with technological solutions that are related to Industry 4.0. Additionally, an increase of the workload from 65% to 90% could be possible through the implementation of these technologies (Roland Berger GmbH, 2016).

Experts assume that the digitalization towards Industry 4.0 is just getting started, even though many technologies are already known. Nevertheless, the single technologies are developing relatively fast and it is difficult to state which technology will be available next, or how these technologies will change the market and the manufacturing sector as a whole. Technologies like Artificial Intelligence have accomplished impressive developments during the last two decades and the future expectations for these technologies are even higher. Therefore, it is even possible that the fourth industrial revolution is revolutionized during the revolution itself (V. P. Andelfinger, 2017).

2.1.1. The previous three industrial revolutions

The first industrial revolution started at the end of the 18^{th} century with the invention of the steam engine, machine weaving, railroads looms and other mechanical innovations (Barthelmäs et al., 2017; Kumar, 2017). The necessity of these new technologies was lying in a rapidly growing export sector for industrial goods and in a fast-growing population (Barthelmäs et al., 2017). This industrial revolution changed how people were working from scratch. People who previously had lived and worked on the countryside moved to metropolitan areas hoping for a better life and a new job. Potentially in the newly built factories that were not there several years earlier. Machines were providing power and energy, and this enabled completely new forms of production, which were previously impossible with only the power of humans, horses and other animals. The conditions in which people lived did not change significantly in the first place, between the countryside and the fast-growing cities, and in many cases these circumstances even worsened. Nevertheless, the productivity and the creation of value increased significantly as a consequence of the first industrial revolution (V. P. Andelfinger, 2017).

The second industrial revolution started around the turn of the 19th to the 20th century (V. P. Andelfinger, 2017). The foundation of the second industrial revolution can be found in the unification of mechanics and business administration (Barthelmäs et al., 2017). The best-known examples for the second industrial revolution are the increasing use of electric energy and of course Henry Ford's assembly lines and the beginning of mass production (V. P. Andelfinger, 2017; Kumar, 2017). Work was divided into many small steps and each worker had to perform only one working step for a single product instead of working with it from the original state of the product until the delivery state of the product (V. P. Andelfinger, 2017). These famous assembly lines of Henry Ford enabled low costs mass production in the first place (Barthelmäs et al., 2017). This method of production allowed for rapid teaching of newly signed workers, as they only needed to specialize on a single production step of the whole production process. Consequently, the creation of value increased once more significantly (V. P. Andelfinger, 2017).

The third industrial revolution started in the seventies of the 20th century (V. P. Andelfinger, 2017). This industrial revolution was based on the unification of mechanics with electronics and control components (Barthelmäs et al., 2017). The increasing use of computers, automatization and process optimization changed the concept of work again significantly (V. P. Andelfinger, 2017). Automatization in production was based on the development of sensors, actuators and new control technologies. Industrial robots, computer aided manufacturing, computer aided management processes and automated assembly lines were other important technologies that were introduced during the third industrial revolution. Another significant technological achievement was satellite technologies in the field of space travel. Furthermore, a whole new sector was growing through the invention of microelectronics, the IT sector. The technological achievements in this sector are, for instance, personal computers and mobile telecommunication. In the energy sector new technologies were developed in order to use the advantages of renewable energy sources. This development was caused by the growing awareness that fossil resources on this planet are destined to run out, that the use of fossil energy sources has negative impacts on the environment and that nuclear energy is not as safe as people believed. But especially one technology changed the way essentially how people were communicating with another, the Internet. This invention did not only have a great impact on the industry but also on society as a whole. In terms of effects on the society, globalization was the biggest social change caused by the third industrial revolution (Barthelmäs et al., 2017). Nevertheless, in many sectors the third industrial revolution and the related technologies have not reached their full potential yet and are still developing (V. P. Andelfinger, 2017).

2.1.2. Industry 4.0 – The fourth industrial revolution?

Industry 4.0 is often used as an equivalent for the term fourth industrial revolution, therefore 4.0 is added to the word industry (V. P. Andelfinger, 2017). However, the question is frequently raised whether Industry 4.0 is even an industrial revolution in the dimension of the previous three industrial revolutions or if Industry 4.0 is more an evolutionary process. Therefore, in this part of the thesis the three previous industrial revolutions will be analyzed, to identify which stages they all have in common. Afterwards, these common stages will be compared to the concept of Industry 4.0 in order to find out if Industry 4.0 is meeting the requirements for an industrial revolution in the dimension of the previous three industrial revolutions (Barthelmäs et al., 2017)

Studying the past three industrial revolutions one thing in particular can be noticed and that is that, the time between the different industrial revolutions is decreasing from industrial revolution to industrial revolution. Between the first and the second industrial revolution there were approximately 100 years, whereas between the second and the third industrial revolution this timespan almost halved. And as most companies are still within the third industrial revolution and facing optimization challenges within that field, the fourth industrial revolution is already starting (V. P. Andelfinger, 2017). Moreover, all three previous industrial revolutions were happening in three common stages. The first stage was started by one or several disruptive technological changes. Then in the second stage, these technological changes had effects on different fields in society like labor, the social order, energy supply, transport, communication or politics. And finally, in the third stage, these different effects led again to changes on another level, to the so called social changes in a society (Barthelmäs et al., 2017).

Now these three common stages from the past three industrial revolution are applied to the concept of Industry 4.0 in order to find out if Industry 4.0 is already an industrial revolution in the dimension of the previous three industrial revolutions or if it is more an evolutionary development (V. P. Andelfinger, 2017).

The first stage of the past three industrial revolutions were one or several disruptive technological changes (Barthelmäs et al., 2017). Industry 4.0 is mainly driven by four clusters of disruptive technologies: Data and connectivity, analytics and intelligence, human machine interaction and digital to physical conversion (McKinsey Digital, 2015). Nevertheless, all the known technologies of the four clusters named are not totally new; they are existing already for a couple of time. A lot of key parts of Industry 4.0, like the Internet and computing are also characteristics of the third industrial revolution. The technologies themselves are not new, they have evolved and are nowadays more advanced and applicable than they used to be. Therefore, Industry 4.0 is not meeting the requirements for the first stage of an industrial revolution yet (Barthelmäs et al., 2017). However, technologies are developing rapidly and it is difficult to state which technologies will be available in the near future and how these technologies will change the market. Consequently, these disruptive technological changes could happen any time (V. P. Andelfinger, 2017).

The second stage of the past three industrial revolutions were the effects on the different fields in society, which were caused by technological changes. As Industry 4.0 is not located in the past and is still an ongoing process, the effects on different fields in society like labor, the social order, energy supply, transport, communication or politics cannot be totally clarified yet. Upon further analysis of disruptive technologies which are driving Industry 4.0 it can be easily noticed that three things are increasingly developing and becoming more and more crucial; connectivity, automatization and flexibility. As a consequence of these technological improvements, the value chain is rapidly shifting and fulfilling the individual requests of the consumer becomes more relevant than ever. Requests and wishes of customers and companies can be faster implemented in the future and therefore customers and companies are expected to see individualization as a standard and not as a luxury option anymore. Consequently, as effects on the different fields in society can be witnessed already and are projected to increase further, Industry 4.0 is meeting the requirements for the second stage of an industrial revolution (Barthelmäs et al., 2017).

The third stage of the past three industrial revolutions was the so called social changes in a society, these social changes were caused by the effects of the disruptive technological changes on the different fields of society. In the past industrial revolutions an unexpected and abrupt structural social change occurred. These social changes led to a rapid development in the society (Barthelmäs et al., 2017). With Industry 4.0 and the ongoing automatization more and more industrial robots and intelligent software will be used in the industry. On the one hand, this could lead to a huge loss of jobs mainly for employees who are directly working in the manufacturing process operating machines. On the other hand, Industry 4.0 and digitalization could create new jobs, mainly for highly qualified engineers. Which means workers would move from being directly involved in the production processes to supervise and control the newly automated and interconnected production processes (Gamillscheg, 2017). This shift of labor forces would be a massive social change for the society as a whole. But the entire development of digitalization and Industry 4.0 is still ongoing and the possible social changes in a society can hardly be predicted as they are happening at the third stage of an industrial revolution. Moreover, these social changes in the society are not happening from one day to another or without any evidences. An evidence for future social changes in society could be the ongoing shift in consumer demand towards individualization and specialization, which is increasing the last couple of years and it is assumed that this development could escalate even more. Therefore, it is hard to predict if Industry 4.0 will meet the requirements for the third stage of an industrial revolution one day. But the changes in consumer demand and the consequences of these changes are indicating that Industry 4.0 will meet the third stage requirement for an industrial revolution in the future (Barthelmäs et al., 2017).

All in all, Industry 4.0 is currently only meeting the requirements of one out of three stages which all the previous three industrial revolutions met. The requirement for stage one was not met because one or several disruptive technological changes could not be identified yet and the key technologies of Industry 4.0 are developments of technologies from the third industrial revolution and not completely new technologies. Additionally, the requirement for stage three was not met because no social changes caused by Industry 4.0 and the related technologies have happened yet (Barthelmäs et al., 2017).

It is debatable how Industry 4.0 can be classified now. Considering the current state Industry 4.0 is not an industrial revolution in the dimension of the previous three industrial revolutions. Obviously, Industry 4.0 is at the moment more similar to an evolutionary process, as it is carried out in many small, ongoing and progressive steps and is not a radical change. But the concept of Industry 4.0 has the potential of meeting the requirements for an industrial revolution in the future as technology is developing fast and radical technological changes can hardly be predicted. To sum up, the concept of Industry 4.0 is contemporarily more like an evolution of the third industrial revolution and therefore Industry 3.1 would be a more accurate term to use. But as the future is hardly predictable and disruptive technological changes and industrial revolutions come fast and unexpected Industry 4.0 could faster become the fourth industrial revolution than it is now expected to be (Barthelmäs et al., 2017).

2.2. Digitalization

The concept of digitalization (sometimes also named digitization) in the context of management typically focuses on the conversion of manual processes and physical objects into digital versions of these processes and objects. This conversion is done with the help of digital technologies like cloud computing and Big Data among others (Schawel and Billing, 2017).

Digitalization in a manufacturing company describes the process of transforming a centrally controlled and automated production known as Industry 3.0 into a self-controlled and flexible production known as Industry 4.0. In this self-controlled and flexible production all products, systems and steps throughout the whole process are digitalized and interconnected (Leyh et al., 2016). Digitalization is the foundation for newly developing disruptive technologies and business models which are contemporarily starting to replace traditional business models (Oppitz and Tomsu, 2017). This trend, towards an increasingly digitalized environment will boost the growth and the availability of digital products and services (Lasi et al., 2014).

Moreover, the process of digitalization will affect the entire value chain as well as the whole supply chain of a company. Digitalization of the complete product life cycle describes an intelligent cross-linked interconnection across all phases of the product life cycle. Starting with the acquisition of the raw materials which are needed for the production of the product, over the manufacturing process of the product, through the initial use of the product by the customer, until the final disposal of the product (BITKOM et al., 2015; Stock and Seliger, 2016). Additionally, the implementation of intelligent cross-linked end-to-end solutions is expected to become more and more popular among companies in order to bridge the connectivity gap within a company (Ebner et al., 2013; Stock and Seliger, 2016). Hence, in order finalize the process of digitalization, reach the full digital maturity and meet the conditions that fully support the concept of Industry 4.0, a manufacturing company needs to digitalize their company throughout the whole supply and value chain in a vertical and in a horizontal way (BITKOM et al., 2015; Schumacher et al., 2016; Stock and Seliger, 2016).

The process of digitalization in the manufacturing sector and the subsequent digitalization of the production and the production supporting tools is resulting in an increasing amount of data which is collected by the newly implemented sensors. This collected data can support analysis and operations and builds the foundation for many disruptive digital technologies (Lasi et al., 2014). This digitalization of the manufacturing sector is driven by a set of four clusters of disruptive digital technologies: Data and connectivity, analytics and intelligence, human machine interaction and digital to physical conversion. The most relevant digital technologies will be analyzed and discussed in detail in Chapter 2.4. (McKinsey Digital, 2015).

Debatable is how companies can actually benefit from these digital technologies and how significant the impact of digitalization on the performance of a company is. A couple of surveys, studies and estimations are focusing on the raised issues as well as on the topics digitalization and Industry 4.0 in general.

An international survey of PwC with over 2000 participants worldwide found out that 35% of the companies within the manufacturing sector expect additional revenues followed by the implementation of digital technologies until the year 2021. Moreover, 43% of these companies project a reduction of costs through digitalization within that period and 53% of the companies within the manufacturing sector are expecting efficiency gains through the implementation of digital technologies until the year 2021 (Geissbauer et al., 2016). In addition, the cooperation Capgemini Consulting is projecting based on their project experience that cost on capital can be cut by as much as 30% due to the implementation of digital technologies into manufacturing processes (Ebner et al., 2013). By implementing these technologies, the average projected total cost reduction until the year 2020 in the manufacturing sector is expected to be 3.6% per year (Geissbauer et al., 2016). Concerning the cost of goods sold, these cost are presumed be reduced by 20% through the implementation of digital technologies into the manufacturing process (Ebner et al., 2013). Furthermore, the European Parliamentary Research Service found out that the digitalization of manufacturing processes could reduce the number of defects and errors significantly (Davies, 2015). Moreover, 55% of the companies are projecting that their investments in Industry 4.0 are paying back within two years (Griessbauer et al., 2016). Additionally, an increase of the workload from 65% to 90% could be possible through the implementation of digital technologies (Roland Berger GmbH, 2016).

To sum up, these surveys, studies and estimations overall paint a relatively bright image of the possibilities which are related to the process of digitalization and the implementation of digital technologies. The presented figures show that digitalization in general, offers great opportunities to manufacturing company, as the digitalization of products, services and processes provide new sources of revenue streams, new ways of cutting costs and significant efficiency gains. These figures also show how high the expectations of manufacturing companies, consulting corporations and organizations are for the future. These future expectations are based on the promising process of digitalization and the underlying digital technologies which are paving the way towards Industry 4.0.

2.2.1. Economic impacts of digitalization

Through the development towards an intensifying implementation of digital technologies in companies the process of digitalization will sooner or later also lead to impacts on the whole economy. Nowadays the overall impact of digitalization and the related digital technologies on the whole industry is already massive and is expected to increase even more. Digitalization is now influencing the processes of a company and the relation of a company towards their customers and towards their suppliers. But digitalization and digital technologies do not only have an impact on the company, on its suppliers and on the customers of this company, digitalization is also having impacts on the economy as a whole (Oppitz & Tomsu, 2017).

Currently three out of four persons in the world have already access to the Internet and half of them are already using social media in an active way. Additionally, already 90% of the Internet users buy goods online (Büyüközkan & Göçer, 2018). Figures like the previous ones show in an impressive way how advanced the process of digitalization already is and which impact it is having on the economy.

Moreover, until the year 2021 companies from all over the world project a massive increase of digitalization, as these global companies are expecting an increase of the digital level in 2016 until the year 2021 by 38% in average (Griessbauer et al., 2016). Additionally, research indicates that the digitalization of the manufacturing sector and the development towards Industry 4.0 is becoming an increasingly growing economic field as only in the year 2014 in Germany 430 million Euros were invested into digital technologies which are related to Industry 4.0. Furthermore, it is expected that the investments in Germany into these digital technologies will increase to 2.62 billion Euros in 2020 (Statista, 2014). Globally it is estimated that companies from all over the globe will invest over 900 billion US-Dollars per year into technologies which are related to Industry 4.0 by the year 2020. These massive amounts of capital invested into the process of digitalization and subsequently into the underlying digital technologies are expected to stimulate the growth of industries which are related to these technologies (Griessbauer, Vedso, & Schrauf, 2016).

The overall economic potential of Industry 4.0 is enormous, through the implementation of digital technologies which are related to Industry 4.0 the capital efficiency in Western Europe could increase from 18 percent in the year 2016 up to 28 percent in the year 2035. Consequently, this growth in capital efficiency would lead to higher profits and less bounded capital. Moreover, the increase in capital efficiency would make enormous amounts of capital available for new investments. This whole development could create an additional value added of 420 billion Euros until the year 2035 (Roland Berger GmbH, 2016). Furthermore, experts are expecting Industry 4.0 and the related technologies to increase the revenues of manufacturing companies by 23 percent and their productivity by 26 percent (McKinsey Digital, 2015). Beside that also an increase in yield in the manufacturing sector is possible; this could be achieved through the implementation of technologies which are related to Industry 4.0. The consulting company Roland Berger GmbH illustrates in an example about a supplier in the automotive industry how the yield on capital used can be increased from 25% to 40%. This growth was achieved through upgrading the manufacturing process with technological solutions which are related to the concept of Industry 4.0 (Roland Berger GmbH, 2016).

All in all, the economic impacts of digitalization and the development towards Industry 4.0 are expected to be enormous. As due to the massive investment in digitalization, the digital level of companies and consequently the digital level of the whole economy will increase. Through these investments massive efficiency and productivity gains can be achieved for companies and for the economy as a whole.

2.2.2. Social impacts of digitalization

Digitalization and digital technologies do not only have an impact on companies, on their business partners, on customers and on the entire economy. Digitalization is also having impacts on whole societies. Moreover, the social impacts of digitalization are highly related to the economic impacts of digitalization, as technological changes usually cause economic changes and in the end these economic changes result in social changes (V. P. Andelfinger, 2017; Barthelmäs et al., 2017). Throughout history there has been no industrial revolution which was not resulting in social changes. These industrial revolutions always change whole societies and therefore they led to enormous social impacts. These changes and developments have been demonstrated in the previous part of this chapter (V. P. Andelfinger, 2017). The pattern that industrial revolutions result in social changes can be observed from the first, over the second, until the third industrial revolution and also concerning the fourth industrial revolution massive social changes are expected (Barthelmäs et al., 2017).

Furthermore, the process of digitalization and the development towards Industry 4.0 have the full potential for having similar effects on society like the previous three industrial revolutions. Some factors even indicate that the changes caused by digitalization and the related technologies could even lead to the most fundamental social changes in the history of all industrial revolutions (V. P. Andelfinger, 2017). This projection is related to the expectation that a significant amount of the workforce could be replaced by computers and robots. As a consequence, that would result in a huge number of unemployed people. A development like this would lead to a new dimension of social changes (Creutzburg, 2018). During the past three industrial revolutions it was always relatively simple to replace obsolete jobs with new ones, as it was relatively easy to educate the new employees for their new profession. This development accrued because the newly created jobs were relatively fast to learn and not too complex to execute. An example for this shift during the first industrial revolution is that a significant amount of the workforce stopped working on the fields and started to work in factories. Both jobs required hard physical work and the new factory jobs were fairly simple and sometimes even less complex than the work of a farmer. Then during the second industrial revolution work was divided into many small steps. These small steps could be easily learned by the already existing workers in the factories as well as by newly trained workers. Then the relatively slow shift towards the third industrial revolution gave the people enough time to prepare themselves for the automation of processes, so these people could move into new jobs over time. But nowadays the technological development speeds up and it is highly debatable when and how hard the effects of the fourth industrial revolution will hit society. Especially, when the fact is taken into consideration that the time between the industrial revolutions is getting increasingly shorter. This means that individuals, businesses and whole societies have less time to prepare themselves for the technological and for the following social changes, which are the consequences of the technological changes. The technological development is accelerating and disruptive changes are likely to happen more frequently and faster (V. P. Andelfinger, 2017). Examples for this development are the field of robotics as well as the field of Artificial Intelligence (V. P. Andelfinger, 2017; Russel and Norvig, 2012).

Moreover, digitalization and the development towards Industry 4.0 have the potential of making a huge amount of jobs obsolete, especially jobs with low requirements of skills. An example therefore would be the company Uber, which already is providing a cheaper taxi service and is contemporarily starting to introduce autonomous driving solutions (V. P. Andelfinger, 2017). Moreover, Uber is not the only technology company which is active in the field of autonomous driving. Beside them also technology giants like Apple and Google joined the field of autonomous driving and are working on technological solutions within that field. The presence of these technological giants in the field of autonomous driving shows how high the expectations are for the future within the field of autonomous driving (Seif and Hu, 2016). Additionally, Uber already started to invest into the development of a flying vehicle, which is expected to execute taxi related services in the future (Wakabayashi, 2017). Other examples of low skilled jobs which are likely to be outdated in future are cashiers at shops and supermarkets. These jobs are likely getting replaced by self-checkout counters (V. P. Andelfinger, 2017). In addition, cleaning duties could be executed in the future by cleaning robots and call-centers could be run by technologies which are relate to the field of Artificial Intelligence (V. P. Andelfinger, 2017; Prabakaran et al., 2018; Russel and Norvig, 2012).

Furthermore, the jobs which are likely to be needed in future are not suitable for the majority of the people who are dropping out of jobs which are having a low requirement of skills; especially these kinds of jobs are expected to get obsolete. This phenomenon that a huge amount of low skilled people cannot find a suitable job is already pressuring society and politics today. Only in a few fields a shortage of labor is observed and in the future this shortage is likely to remain in certain high skilled professions (V. P. Andelfinger, 2017). Already today this phenomenon can be observed in Austria. On the one hand, currently in 2018 the manufacturing companies in Austria cannot find 10,500 to 11,000 highly skilled workers, which are already needed in order to grow the sector and to meet customers demand. This means that 15 to 20 percent of the yearly demand for highly skilled workers of the whole manufacturing sector in Austria cannot be met by the supply in highly skilled workers (Strobl, 2018). On the other hand, over 300,000 people in Austria were in April 2018 registered as unemployed (Eichinger, 2018). Hence, already nowadays where the process of digitalization is just getting started it is extremely hard to match unemployed people with highly skilled jobs in the manufacturing sector (Eichinger, 2018; Strobl, 2018). Moreover, digitalization and the development towards Industry 4.0 are catalyzers which are increasing the speed of the increase of unemployment. Moreover, it is very likely that the job profile of high skilled jobs is becoming more demanding than ever and that only a few people today will meet the requirements of the future (V. P. Andelfinger, 2017).

Throughout the previous three industrial revolutions people who lost their jobs could be qualified relatively quickly and had the opportunity to profit from these changes. Concerning the process of digitalization and the development towards Industry 4.0 this could easily change as an increasing number of low-skilled manufacturing jobs are expected to get obsolete (V. P. Andelfinger, 2017). In the meanwhile, the digitalization of the manufacturing sector towards Industry 4.0 already is becoming reality in China today, as the Taiwanese supplier of Apple and Samsung Foxconn replaced 60,000 jobs of factory workers with industrial robots (Wakefield, 2016).

Another trend in the manufacturing sector which is highly related to the previous one and based on automatization and digitalization is the trend of moving back manufacturing to high-cost countries. An example for this development is the German sportswear manufacturing company Adidas, which is planning to open a digitalized shoe factory in Germany and a similar one is planned in addition in the United States of America near Atlanta, Georgia. Nowadays production in developed countries like Germany and the United States becomes more attractive again. This trend is caused by two developments. On the one side, wages in former developing countries like Vietnam and China are rising and this makes production in these countries more expensive for manufacturing companies. On the other side, the process of digitalization makes producing in high-cost countries cheaper again as due to digitalization the cost factor wages for workers becomes less important in the calculations of these companies. Consequently, at the same time overall manufacturing costs in former low-cost countries are on the rise and simultaneously overall manufacturing costs in high-cost countries are becoming increasingly economic again due to the factor digitalization. If these factors are combined it is likely that the trend of moving back manufacturing to high-cost countries is accelerating (The Economist, 2017). But in the long run the development of moving manufacturing to places where the good is consumed will not bring a lot of jobs back to high-cost countries like Germany and the United States, as in digitalized factories human workers are replaced by robots. So maybe the only job who is created at the end in a digitalized factory is the one of the security guard, guarding the gates of this digital factory. Whereas in Vietnam, China and other emerging economies hundreds of thousands of jobs get lost due to that process (V. P. Andelfinger, 2017; The Economist, 2017).

Furthermore, a lot of studies, surveys and projections have been made in order to estimate the effects of digitalization and the development towards Industry 4.0 on the society. For instance, a German digital sector association is projecting that within the next five year 3.4 million jobs will be lost in Germany due to the process of digitalization, this equals approximately 10% of the German workforce (Löhr, 2018). A study of the University of Oxford from the year 2013 came to the conclusion that in the next two decades every second job in the United States of America is at stake due to the process of digitalization and the development towards Industry 4.0 (Benedikt Frey et al., 2013). Overall, a significant number of studies assume that digitalization and Industry 4.0 will cost millions of jobs worldwide. The most extreme studies even predict a job loss of 40% to 60% worldwide (V. P. Andelfinger, 2017).

But, among scholars it is still highly debated if the process of digitalization and the development towards Industry 4.0 is changing the job market in a fundamental way like many estimations predict it. Moreover, it is also discussed what this development means for employment in general if this radical digital change accrues in the way like many predict it (Bernau, 2018). But not all studies predict only a loss in jobs, some studies indicate that digitalization already created over 6 million worldwide and that digitalization in general creates jobs and helps reducing the unemployment rate (Sabbagh et al., 2013).

To sum up, it can be stated that on the one side there are a lot of studies that come to the conclusion that a significant number of jobs are at risk. On the other side the expectations for newly created jobs are relatively limited and far less concrete than the studies that project a reduction of jobs. In addition, it is extremely hard to project which new business models are going to be developed in the future and it is even harder to say which of these business models are going to be successful in the future and which are going to fail. Consequently, it is even harder to project how many jobs these newly developed successful business models will create and which qualifications these positions require of future employees (V. P. Andelfinger, 2017).

But unemployment is not the only field where social changes are expected from the process of digitalization and the development towards Industry 4.0. Also, the distribution of wealth will be heavily debated in future. Many factors indicate that the creation of newly created wealth will be huge, through digitalization. But to which extent the members in a society participate in this increase of wealth is highly questionable (V. P. Andelfinger, 2017). Already today, the eight richest men in the world have more wealth than the poorest half of the whole planet. This poorer half of the planet consists contemporarily of 3.6 billion people (Knop, 2017). In the last decades the overall productivity has become progressively more. But the growth of productivity is much faster than the growth of the wealth of working people within a society. As a consequence, the wealth of people who participate from these productivity gains i.e. owner of company shares is increasing faster than the wealth of working people. This discrepancy is contemporarily even accelerated through the process of digitalization and the development towards Industry 4.0. (V. P. Andelfinger, 2017).

All in all, the impacts of digitalization on the society have the potential to be enormous, as it is possible that unemployment rates are rising to 20-30%. At least politics and societies in general should prepare themselves for possibilities like this (V. P. Andelfinger, 2017). Additionally, the process of digitalization and the development towards Industry 4.0 are leading to the development of new business models, products and services. For the development and maintenance of these businesses, products and services certain new occupations are created. But this development is connected with the disappearance of a huge number of low and middle-skilled professions (Katz, 2017). Moreover, the debate about the future of employment is highly connected to the issue of wealth and the distribution of wealth. As generally, money can be earned in two ways, the first way is with work and the second way is with capital. Whoever owns capital can let his capital work for him or her. But the big majority of the people earn most of their money with ordinary work. And if ordinary workers get replaced by digital technologies then these people and consequently society will face a serious problem. So the question is how will policy makers react to the challenges which digitalization and the development towards Industry 4.0 give them to handle (V. P. Andelfinger, 2017). Moreover, society itself is facing the question how a future society in a digitalized environment should be developed and how this society should look like in future. Already today alternative forms of income are being heavily debated, has the questions arises how people in obsolete low and middle skilled should generate their income when a significant number of jobs are digitalized. The most discussed approach towards the future of employment in Europe is contemporarily the concept of a basic income which is provided for every citizen by the state (Löhr, 2018). This concept of a basic income became relatively famous when the Swiss population voted in a referendum on the 5th of June in 2016 against the introduction of a basic income (Die Zeit, 2016). In addition, generally digitalization is expected to favor the workers with a higher level of education and more training (Katz, 2017). Hence, with a high educated and increasingly skilled workforce with digital competences, the potential negative effects of digitalization could be reduced. This could be accomplished through investments in education, for example into schools and universities. These investments should prepare students in the best possible way to handle the challenges of a labor market in which digital competences become ever more important. Another method to reduce the effects of digitalization on the unemployment rate could be the reduction of working hours per person. Concepts like this are already discussed in European countries, mainly in the Scandinavian ones. For example, in Sweden a six-hour day with full compensation of payment has already been tested. The reduction of working hours in an increasingly digitalized environment would be mainly done in order to distribute the remaining jobs better among the workers who meet the requirements for these jobs. But a development like this would leave the single employees either with less income, as they are working less hours. Or the employer has to pay higher wages. Especially this development would make the work of humans even more expensive and consequently the attractiveness of digitalized alternatives would even increase (Kallis et al., 2013; Savage, 2017).

2.3. Digital intensity within the manufacturing sector

Manufacturing companies usually have an inconstant relationship with technology. On the one hand some technologies have been adopted widely throughout the whole sector like Production Planning systems and Enterprise Resource Planning (ERP). For instance, a survey which was conducted among 170 international manufacturing companies found out that 92% of these companies have already working with ERP systems. But on the other hand, other technologies like Big Data, Artificial Intelligence and 3D-printing are rarely implemented yet. Therefore in this part the digital intensity of the manufacturing sector will be analyzed and put into relation with other sectors (Ebner et al., 2013).

A factor to consider when it comes to the digital intensity of the manufacturing sector is how manufacturing companies see themselves prepared for the digitalization. A study of the cooperation McKinsey & Company of German, US-American and Japanese companies found out that 58% of the manufacturing companies see themselves prepared for the process of digitalization and the related challenges. But this value is varying to a huge extent based on in which country a manufacturing company is located. 83% of the US-American companies see themselves prepared for the process of digitalization and the development towards Industry 4.0. Moreover, 57% of the German companies see themselves prepared and only 34% of the Japanese (McKinsey Digital, 2015; Niebauer and Riemath, 2017).

Moreover, most of the manufacturing companies are using digital technologies only partially. As usually the processes are digitalized at a different time and to a varying extent. This incomplete use of digital technologies creates a connectivity gap within the information flow and consequently also within the operations of the company, which has implemented digital technologies only to a varying extent (Ebner et al., 2013). How low the digital development of manufacturing companies is compared to companies from other sectors like for example the information and communication sector has been shown in a survey from Germany. This survey has been conducted among 1806 companies in the year 2017. The survey found out that only 1% of the companies within the manufacturing sector estimate themselves as fully digitalized. Compared to the information and communication sector where 24% of the companies estimate themselves as digitalized the manufacturing sector scores extremely low (Statista, 2017b). Additionally, research of the MIT (Massachusetts Institute of Technology) Center for Digital Business and the Capgemini Consulting company found out that only 12% of the companies within the manufacturing sector are really taking advantage of the opportunities which digital technologies are offering to them. Compared to other sectors like banking, telecom and insurance the manufacturing sector is scoring in particular low when it comes to digital intensity. As in the telecom, the banking and the insurance sector over 30% of the companies are truly taking advantage of the opportunities which digital technologies offer to them (Ebner et al., 2013).

Additionally, the research of Capgemini Consulting indicates that 62% of the companies within the manufacturing sector are implementing digital initiatives not across regions and functions. Implementing digital initiatives in that way limits the free information flow through different departments and company units. Consequently, connectivity gaps are created with digital initiatives that are not implemented across regions and functions. As a result, companies within the manufacturing sector are contemporarily relatively slow in adopting digital technologies like for instance Artificial Intelligence, Big Data, Internet of Things solutions or real-time order confirmation. The specific effect of this circumstance is the so-called connectivity gap. Digital technologies help companies to bridge the connectivity gap between operations. It is projected that closing the so-called connectivity gap has the potential to reduce costs by as much as 30% through enabling savings on capital costs and labor force. Closing the connectivity gap is a core part of the process of digitalization and the development towards Industry 4.0 (Ebner et al., 2013).

Consequently, one can state that the manufacturing sector is generally a beginner when it comes to digital intensity and that other sectors are already ahead when it comes to implementing digital technologies (Ebner et al., 2013). So as digitalization drives the changes towards Industry 4.0, manufacturing companies are expected to catch up in terms of digital intensity (Leyh et al., 2016). The following part of this thesis deals with the four clusters of disruptive technologies: Data and connectivity, analytics and intelligence, human machine interaction and digital to physical conversion. Each of these four clusters will be discussed in an own subtopic. And within these subtopics the most promising disruptive digital technologies which have the potential of transforming the manufacturing sector are going to be presented and analyzed in detail.

2.4. The four clusters of disruptive technologies

In general, there are four clusters of disruptive technologies. The first one is data and connectivity, the second one is analytics and intelligence, the third one is Human Machine Interface (HMI) and the fourth cluster is digital to physical conversion. Each of these clusters functions as a collection of various technologies with similar characteristics. The borders between these four clusters are liquid and some technologies share characteristics of more than just one cluster. However, each technology will be described, analyzed and discussed within the cluster where the main characteristic of the technology is situated in (McKinsey Digital, 2015).

2.4.1. Data and Connectivity

The cluster data and connectivity contains technologies like Big Data, the Internet of Things (IoT), smart sensors and cloud computing among others. This cluster is predominantly driven by an enormous reduction of costs. Sensors, hardware, digital storage and the transmission of data are just a few examples of fields where an enormous reduction in costs enables huge chances for companies who use and know how to use these technologies in an effective way. These technologies give companies the opportunity to collect, store and analyze data. This process happens without the use of human labor, as physical objects can observe and scan their environment and communicate via wired and wireless networks with each other autonomously (McKinsey Digital, 2015).

2.4.1.1. Big Data

In the last several years the terminology Big Data has been increasingly used and the topic Big Data is becoming more and more important. In the same period, the overall amount and the accessibility of data increased exponentially (Ribeiro et al., 2015). Especially among businesses the use of Big Data solutions increased massively, from 17% in 2015 to 53% in 2017 (Columbus, 2017). The rapid growth in the quantity of data is mainly the consequence of the impressive technological developments in fields like computing, mobile devices, social networks and sensors. All these sources continuously produce more and more structured, semistructured and unstructured data. (Ribeiro et al., 2015). Generally, Big Data is defined as "the very large amounts of data, both structured and unstructured, that organizations are now capable of capturing and attempting to analyze in a meaningful way so that data-driven decision analysis and actionable insights can be obtained" (Storey and Song, 2017). Consequently, investments in Big Data can be very promising as Big Data based solutions can create huge benefits for the company which implements them. Big Data based technologies can discover hidden patterns and correlations in the datasets which are analyzed. Users of Big Data have the possibility to use this knowledge to gain a deeper understanding of their business and to generate advantages for their companies (Ribeiro et al., 2015).

As Big Data requires investments in the storage of data, in processing and visualization technologies, Big Data is one of the huge challenges companies nowadays face (Ribeiro et al., 2015). Consequently, one of the key questions for manufacturing companies concerning Big Data is how does the implementation of Big Data could look in practice. In the manufacturing sector as in any other industrial sectors data can be collected and analyzed in order to produce more efficiently. The key difference in that example is that the largest amount of data is not inserted manually by customers or employees; it is put into the system automatically through the use of sensors. But the use of sensors is nothing new, as usually in the field of automatization technologies the data of the sensors is used to regulate the production. These regulators can be implemented mechanically, electrically or through an algorithm. Sensors collect the status quo of a process step i.e. the temperature of an oven and pass this information on to the regulator. The regulator compares the status quo with the target value and adjusts if necessary the power of the oven. All these steps are executed automatically and without manual interference (Hänisch, 2017).

Normally, the values of the temperature or the power of the oven are perhaps collected but typically they are not analyzed or put into relation with other values. Usually, the collected data is saved in a single silo and from outside no one can access it. But exactly the access from outside would be necessary for the use of Big Data technologies (Hänisch, 2017). Particularly this point is a key difference between Industry 3.0 and the concept of Industry 4.0. As closing down the connectivity gap is a core part of the concept of Industry 4.0 (McKinsey Digital, 2015). Previously, the collected data has been just used for the controlling of processes. Now, in the time of Industry 4.0 this is changing, as the collected data is saved and made accessible also for other applications. Moreover, systems are not only connected within the production, they are also interconnected throughout the whole company (Hänisch, 2017).

The consulting company McKinsey & Company presented a case of an anonymous European producer of chemicals who was already performing better than the benchmark of the chemical sector before Big Data solutions were implemented. Now the chemical company applied techniques which were based on Big Data technologies in order to measure the influence of different production inputs like temperatures, coolant pressure and carbon dioxide flow on the production output. The analysis of the collected data revealed previously unseen patterns. As a result, the chemical company adjusted their inputs according to the outcomes of the analysis. Now the company was able to reduce their energy costs by around 15 percent and the amount of raw materials wasted by 20 percent. As a consequence, the company also improved their overall results (Auschitzky et al., 2014).

Therefore, the benefits of Big Data are obvious as hidden patterns and correlations can be discovered in the already existing or in the newly generated datasets of a company. The analyzes of these datasets offers companies the opportunity to gain a deeper understanding of their business. Furthermore, these analyzes highlight potentials which can improve processes (Ribeiro et al., 2015). Contemporarily, Big Data is developing into a valuable business asset for companies. If companies manage to use Big Data solutions in an effective way, they can achieve average productivity gains of 6% (Armstrong et al., 2012; King, 2013). Additionally, research of IBM indicates that companies who use Big Data solutions, implement them into their processes and generate predictions based on Big Data achieved an average increase in revenues of 10.8%. Moreover, the average EBITDA of these companies rose by 12% and their stock price increased in average by 7.4% (Franks et al., 2012; King, 2013). Another benefit of implementing Big Data solutions is that these solutions help companies to shut down the connectivity gap (Ebner et al., 2013; Ribeiro et al., 2015). Hence, Big Data is a promising tool for manufacturing companies to decrease costs and to improve rentability as in the manufacturing sector processes are usually complex, have a certain variability and capacity is typically restraint (Auschitzky et al., 2014).

But beside the benefits of Big Data solutions also the costs of this technology determine if a company adopts Big Data solutions or if they do not implement these solutions. Big Data is one of the huge challenges companies nowadays face as the implementation of Big Data solution requires investments in the storage of data, in processing technologies, in visualization technologies and also in the implementation of sensors that collect the data. In the case of some manufacturing companies, sufficient sensors might be already implemented into the production line but not used for Big Data solutions yet. Of course, the costs of implementing Big Data technologies are extremely varying from company to company. Furthermore, these costs are highly dependable on the complexity of a production process and until the extent to which the required technologies and infrastructure are already implemented into the production line and throughout the whole company (Hänisch, 2017; Ribeiro et al., 2015). But as the whole technological cluster data and connectivity is predominantly driven by an enormous reduction of costs, Big Data solutions are also affected by this trend towards decreasing costs. If these costs continue to decrease, Big Data solutions will become increasingly attractive for manufacturing companies (McKinsey Digital, 2015).

Another factor which can determine the adoption of Big Data solutions is the question if and to which extent business partners already have implemented similar solutions into their processes and operations and if these business partners are willing to share their data.

In addition, an incremental aspect when analyzing digital technologies is which risk is related to that technology. As beside all the advantages and benefits which Big Data and the related technological solutions offer, these technologies also contain a certain amount of risks. Companies should take this aspect into consideration before they implement these technologies. These risks which are involved into the issue of Big Data are worth to be discussed critically. One critical point is that a big stack of data usually contains data from many different sources and some of this data could be of insufficient quality (Bröder, 2015). Furthermore, data from insufficient quality could influence the reliability of the correlations and hidden patterns found by Big Data technologies negatively (Ribeiro et al., 2015). Moreover, there are many reasons why data can be of insufficient quality i.e. the data could not be representative, the data could contain certain errors, the data could be obsolete, or the data could be inconsistent. In many cases the degree of insufficient data quality cannot be evaluated or even estimated. If data is really becoming the oil of the 21st century as some people expect it to become, this oil needs a reliable refinery so that the underlying information within the data can be secured. Additionally, the issue of data security is a high risk for companies who are thinking about implementing Big Data solutions, as the loss of data can be extremely critical for companies. This valuable data can be lost or manipulated through espionage and sabotage (Bröder, 2015; Hänisch, 2017). A famous example for the industrial sabotage of data is the case of Stuxnet, a virus that sabotaged data in an Iranian nuclear facility, located in Natanz. As a consequence, Stuxnet delayed Iran's nuclear program and created massive negative financial and political consequences for the Islamic Republic of Iran (Shakarian et al., 2013).

2.4.1.2. Internet of Things – IoT

The terminology Internet of Things or just IoT has been developed by Kevin Ashton in 1999. He used the phrase Internet of Things as title for a presentation he held at the company Proctor & Gamble (P&G). He wanted to create attention for the by that time newly developed idea of RFID in P&G's supply chain (Ashton, 2009). But the basic concept of the Internet of Things is much older than the terminology Internet of Things. Already back in the year 1991 Mark Weiser developed the idea of ubiquitous computing. His idea was basically an environment of many computers in the form of tablets and sensors which can interact with another (Weiser, 1991).

Throughout the years there have been many different definitions and explanations developed what the Internet of Things is. But as the Internet of Things is an umbrella term, there is no unified definition for the terminology Internet of Things available yet (King, 2013). A frequently used and well-established definition is the definition of Sundmaeker et al. (2010), they define the Internet of Things as ''a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network". Another leaner definition of the Internet of Things is the definition of Oppitz and Tomsu (2017), they define the IoT as "the connection of devices or physical objects with embedded sensors, actuators and software by networking technologies to interact with the internal states or the external environment". Hence, the terminology Internet of Things means that billions of things all over the planet are interconnected through the use of sensors, readers, RFID labels and other digital identifying information technologies (Volker P. Andelfinger et al., 2015; Anderson and Rainie, 2012; King, 2013).

The projections for the future development of the Internet of Things and the related technologies are impressive. In the year 2016 over 6.3 billion devices were already connected worldwide to the Internet of Things, for 2018 it is projected that almost 11.2 billion devices will be connected to the IoT and in 2020 it is estimated that around 20.4 billion devices will be linked to the Internet of Things (Statista, 2017a). Moreover, also other sources project a bright future for the Internet of Things. For instance, Rob Lloyd from the US-based company Cisco is expecting the field of IoT to become a billion Dollar market. He has estimated business opportunities worth of 14 billion US-Dollars which are related to IoT solutions until the year 2020 (Volker P. Andelfinger et al., 2015).

Nowadays, where a high share of the population in the developed and developing world owns a smartphone, high end sensors are literally in every pocket. These sensors can perform a great variety of different tasks like tracking the locations and the speed with which the owner of a smartphone is moving or for instance the temperature of the smartphone (Hänisch, 2017). So, the basic gear in order to benefit from the advantages of the Internet of Things is partially already available. A lot of examples show which value can be created if the data of a big number of smartphones is collected and evaluated. For instance, earthquakes can be investigated or maybe even predicted if the data of a significant number of smartphone acceleration-sensors is combined and evaluated. A method like this is expected to be significantly more precise than the use of several seismometers (Gramling, 2016). The key to these kinds of applications is that the data which the sensors of the smartphones collect are not saved local on each and every smartphone, instead the data is shared with other parties via the Internet. Consequently, the sensors become part of the Internet, part of the Internet of Things But of course, the Internet of Things is not only limited to smartphones as sensors can be implemented almost everywhere, which means that the potential opportunities areas for the Internet of Things are almost endless (Hänisch, 2017).

But how can manufacturing companies actually profit from the implementation of technological solutions which are related to the Internet of Things, how does the implementation of these solutions work in practice and what is changing in the production process due to the implementation of IoT solutions? An example for the practical implementation of the Internet of Things into a manufacturing process would be an automotive manufacturer (Sundmaeker et al., 2010). Contemporarily the use of IoT based solutions is already relatively common in the automotive industry and widely implemented into cars, as nowadays cars can be easily connected to smartphones, offer emergency assistance and give the driver an overview about the traffic situation (Krasniqi and Hajrizi, 2016). But beside the implementation within the vehicle itself, automotive manufacturers are already using a set of technologies in order to implement IoT solutions into the manufacturing process and throughout the whole company. At the moment IoT solutions are used to improve the production process of vehicles, to optimize logistics, to improve the quality control and to develop the customer service in a positive way (Sundmaeker et al., 2010). Furthermore, by implementing an IoT based solution into the IoT environment of a company the whole system will be affected, as IoT solutions are interacting with each other. Moreover, changing one part in this system will affect also the overall system of the company due to the strong interconnection of the different parts within an IoT based system (Kannengiesser and Weichhart, 2015).

The IoT solutions which are attached to parts of a vehicle store information which is related to the part, the product code, a serial number, the manufacturer, in which factory and at which date and time the part was produced and in some cases even the exact real-time location of the part. An example for such an IoT solution would be the use of RFID technology (Kannengiesser and Weichhart, 2015). RFID technologies belong to the field of AIDC technologies and have the ability to identify items, track items and store data (El Khaddar et al., 2011). RFID is capable of a contact free communication via the use of electromagnetic waves (Loebbecke and Huyskens, 2007). Furthermore, RFID technology is capable of providing maintenance information and the real-time physical location of a part throughout the whole production process. The use of this technology offers companies new opportunities for example managing production and recalls in an increasingly efficient way. (Sundmaeker et al., 2010). This is highly related to the fact that the structure of these IoT based manufacturing systems enables the introduction of knowledge based support systems (Kannengiesser and Weichhart, 2015).

Additionally, each and every part of the vehicle can be monitored throughout the whole production process, from the control of the new incoming material, throughout the process of manufacturing until the inspection of the product and the shipping. Moreover, the parts of the vehicle which is produced have the ability to interact with the assembly line during the whole production process (Gupta and Ulrich, 2017). The monitoring of these parts can also be continued when the vehicle is already delivered to the customer, these technologies are capable of monitoring and reporting almost everything, from the pressure in the tires of a vehicle until the physical distance of other vehicles to the own vehicle (Sundmaeker et al., 2010).

Moreover, the technology Dedicated Short Range Communication also known as DSRC offers manufacturing companies the opportunity to implement vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication solutions. The DSRC technology reduces the risk of inference with other technologies; this is realized through the use of higher bit rates. The implementation of these technologies will significantly contribute to the increasing usage of Intelligent Transportation Systems also known as ITS. ITS contain applications like traffic management and vehicle safety services. Furthermore, applications like this will be completely integrated into the Internet of Things. Also, the car itself will be a thing within the Internet of Things. This enables the car to make emergency and breakdown calls itself when they are needed. Moreover, all available data will be collected from the surroundings. The most significant sources of data for a car are the components of the vehicle, the transportation infrastructure like roads and information transmitted by other vehicles. This collected data could become a key asset for manufacturing companies in order to adjust their products due the usage and due to exact customer demand (Sundmaeker et al., 2010).

As in a standard production process without implemented IoT solutions most adjustments in order to improve the production can only be identified when the output is analyzed and controlled at the end of the production. With the implementation of IoT solutions the manufacturing process can become increasingly heterogeneous, responsive and dynamic. With IoT based solutions, problems can be identified much faster and needed countermeasures can be taken automatically by the interconnected assembly line (Gupta and Ulrich, 2017). All in all, IoT based manufacturing systems are generally more heterogeneous and dynamic. Therefore they could be a key technology in order to digitalize the manufacturing sector and lead a manufacturing company and the whole sector towards Industry 4.0 (Kannengiesser and Weichhart, 2015).

Another key question which manufacturing companies should take into consideration is how the production itself and processes within the company change after the implementation of IoT related solutions? The key changes between a manufacturing company which implements IoT solutions and a manufacturing company which has not implemented IoT solutions is that if IoT solutions would be fully implemented, the whole production line would be interconnected and also communicating with the products produced. Moreover, products would be linked via sensors to the Internet. This leads to huge opportunities for manufacturing companies as customized mass production with batch sizes of one is increasingly likely to become reality (Sundmaeker et al., 2010).

One key factor which determines whether or not technological solutions related to the Internet of Things are implemented by a company into their manufacturing process is the question in which way does the company benefit from the implementation of IoT solutions?

One of the most obvious benefits related to the implementation of IoT is that great transparency can be achieved by connecting products via IoT solutions to the Internet, as the location of all the products is available in real time. This could give a company better information about the status of the shop floor and the disposition of lots. The so gained information can be used as an input to reorganize the production schedules and to improve logistics. Moreover, IoT solutions offer companies the opportunity to launch a self-organizing and intelligent manufacturing process. In this self-organizing and intelligent manufacturing process needed parts can be automatically ordered when the need is detected, without any human interference (Sundmaeker et al., 2010).

Additionally, machine to machine communication technologies ensure a relatively secure access to the Internet, independent of the location at relatively low costs (King, 2013; Turner et al., 2012).

The possibility of tracking an object during the whole production process in real-time offers car manufactures to speed up their assembly processes and to relocate vehicles and components faster and more efficient than ever. Furthermore, the usages of IoT solutions cannot only speed up the assembly processes, the use of IoT solutions can take the efficiency of the whole supply chain to a whole new level. Additionally, the benefits of the Internet of Things for manufacturing companies will not stop at the gates of the factory as IoT solutions can be a great asset throughout the whole lifecycle of a product. If products are connected via IoT solutions to the Internet and to an intelligent network infrastructure not only the whole production process can be optimized, also the whole lifecycle of a product can be monitored. Moreover, as these IoT solutions could enable companies to know the whole history and the current status of a product whenever they want, this could give companies the possibility to track the whole lifecycle of a product, from production to disposal. By connecting products via IoT solutions to the Internet the company can gain new insights about the use of their product and can adjust the strategy of the company according to the new information gained via IoT solutions. I.e. the design, the marketing strategy and product related services could all be fields where IoT solutions can contribute a lot of valuable information. Consequently, the insights gained via the Internet could be key assets for a company (Sundmaeker et al., 2010).

Moreover, one of the biggest benefits which IoT related solutions offer to companies lays in the information which is collected from the product when this product already reached the final customer and then the production gets influenced due to the new insights gained. Based on these insights gained from the IoT based solutions, which are monitoring the whole lifecycle of a product, managers can adjust the product, the whole production process in order to improve the efficiency of the company, minimize overall costs or maximize customer satisfaction (Gupta and Ulrich, 2017; Sundmaeker et al., 2010).

Another benefit of implementing Internet of Things solutions is that IoT solutions support companies in reducing the connectivity gap, which would likely to have positive impacts on the operations of a company as it is estimated that closing the connectivity gap can reduce costs by as much as 30% by enabling savings on capital costs and labor force (Ebner et al., 2013).

Additionally, the implementation of solutions related to the Internet of Things will increase the speed of improvement throughout the whole supply chain, as performance gaps get automatically identified by these solutions and the suitable adjustments can be executed immediately (Gupta and Ulrich, 2017).

Another point to consider when it comes to the benefits of IoT based solutions is that the whole supply chain can be optimized as data from the retail stores can be collected in real time by IoT solutions. For example, needed goods can be automatically ordered when the need is detected. Consequently, the ideal amount of products can be delivered and overproduction as well as underproduction can be avoided or at least reduced (Sundmaeker et al., 2010).

Beside the benefits of technological solution related to the Internet of Things also the costs of implementation are a key factor which determines whether or not a company implements IoT products and consequently they can take the level of service to a whole new level. Generally, IoT is like the whole cluster data and connectivity predominantly driven by an enormous reduction of costs (McKinsey Digital, 2015). Nevertheless, solutions based on the Internet of Things require investments in the storage of data, in processing technologies and into the implementation of smart things and sensors among others, who initially collect the data. In the case of some manufacturing companies, IoT capable devices might be already implemented into the products, the production line and in the supply chain but maybe there are still connectivity gaps. Additionally, the possibility that the implemented devices are not used for IoT solutions yet does also exist. Of course, the costs of implementing IoT solutions are extremely varying between different companies, as the costs of implementation are highly dependable on the complexity of a product. In addition, the costs of implementation are also highly dependent on the production process and on the whole supply chain. Furthermore, investments in IoT solutions also have to be in relation to the costs of implementation and into relation to the expected productivity gains. Another point to consider is to which extent are the required technologies already implemented into the operations, into the production line and into the supply chain of a company yet (Ebner et al., 2013; Hänisch, 2017).

Moreover, two trends are strongly supporting the growth of IoT solutions in the future (Hänisch, 2017). Firstly, the cost for the storage of data in general is decreasing at the moment. Hence, it becomes increasingly attractive for companies to store data for a longer period of time. Which makes it more attractive for companies to implement an increasing number of technological devices which are related to the concept of the Internet of Things (Atzori et al., 2010; King, 2013). Secondly, the prices for sensors and technologies which are based on the concept of the Internet of Things are also dropping. This fact is likely to increase the number of companies who implement IoT solutions in the near future (Hänisch, 2017). Through the use of mass production, the price for high tech sensors dropped to below 5 US-Dollars per sensors. This decrease in costs for sensors is related to the increase of supply on the market. The market of sensors is currently driven by consumers products like gaming consoles, computers and smartphones (Volker P. Andelfinger et al., 2015). Moreover, the spread of IoT solutions is strongly interrelated to the decreasing costs of digital communication and digital connection (King, 2013). If the sensors will be also increasingly used in the manufacturing sectors the trend of decreasing prices is expected to continue and IoT solutions will consequently become even more attractive for companies to implement (Volker P. Andelfinger et al., 2015).

But beside all the advantages and opportunities which the technologies related to the Internet of Things offers to companies and their customers, there are also several risks involved which should be considered before implementing IoT solutions. These risks are worth to be discussed in a critical way (Volker P. Andelfinger et al., 2015; Hänisch, 2017).

One of the biggest risks which the implementation of IoT solutions also brings with it, is that there is a high threat that interconnected physical targets like connected machinery in a production facility can become the target of hackers. The aim of these hackers could be industrial sabotage and industrial espionage (McKinsey Digital, 2015). Especially the Internet of Things is a relatively easy target for hackers. Firstly, as the majority of the things connected to the Internet are not supervised and consequently physical attacks are relatively easy to execute. Secondly, communication between devices which are part of the Internet of Things is usually happening wireless; this makes it easier for hackers to espionage the communication between the communicating devices. Thirdly, most of the devices have a relatively low computing power and their energy supply is often limited. Therefore, it is contemporarily impossible to implement complex security programs on most of these devices. Finally, the biggest security gap regarding the Internet of Things is the integrity of data and authentication.

Concerning both of these security gaps the standard personal computer and notebook security solutions are not transferable to IoT solutions yet (Atzori et al., 2010; King, 2013).

Moreover, there are also a couple of risks concerning IoT that have the potential to change society in a fundamental way. For example, the same algorithms which are used for the automated detection of traffic flows and traffic jams can also analyze the behavior of people during big events by using the sensors of their smartphones. The gained data could be used by the organizers of an event and the ambulance services and based on that data they could adjust their strategies. But also, governments could use this technology to predict protests and then the government could take measures according to the predictions. But the use of this technology is not only limited to autocratic regimes. Even in the United States of America technologies like this have been already used by police forces in order to observe the movement of protesters. Furthermore, with the growing availability of IoT solutions and smart things the possibility for observation is even increasing in the future. This development could not only be a problem for protesters and political activists this development could be also becoming a problem for companies as the possibilities for espionage and sabotage are likely to grow (Hänisch, 2017).

Nevertheless, the use of IoT solutions does not necessarily mean that the data is shared with everyone, of course every company and every single smartphone user should have the right to share his data only with the organizations, companies and people they desire to share their data with (Hänisch, 2017).

2.4.1.3. Cloud computing

The terminology cloud is quite commonly known, this fact is caused by cloud services like Dropbox, Google Drive and iCloud and by the fact that the cloud itself already is gaining popularity for over one decade among the users of personal computers and smartphones. But what does the term cloud computing exactly mean? The basic concept of cloud computing is the offer on demand IT infrastructure via the Internet. If these IT resources are needed companies can have access to them on a pay per use base (Hänisch, 2017). The US-American National Institute of Standards and Technology defines cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell and Grance, 2011).

Hence, the term cloud computing describes the providing of IT infrastructure like computing power as an on demand service (da Silva et al., 2016). Therefore, cloud computing has the full potential to develop into a mobile value-added service as the infrastructure, the application and the platform solutions can be delivered on demand on a pay per use basis (Bechtold et al., 2014). The main characteristics of cloud computing are an on-demand self-service, a wide-ranging network access, the sharing resources, a quick elasticity and services (Storey and Song, 2017). Generally, the field of cloud computing can be divided into three fields of different service models. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) (Mell and Grance, 2011).

Therefore, another significant point for companies within the manufacturing sector to consider when it comes to cloud computing is how can the implementation of cloud computing and the implementation of related technologies work in practice and what is changing in the processes of a manufacturing company due to the implementation of these technologies.

Generally, through the rapid development of in communication technologies and sensors, cloud based services like cloud computing are becoming increasingly important for manufacturing companies (Babiceanu and Seker, 2016; Gregori et al., 2017). Especially in the automotive industry cloud computing based solutions are relatively promising for companies and for their customers. This is caused by the fact that autonomous driving requires huge data storage capabilities as well as high amounts of computing power as the data from all vehicles connected to the cloud can be used to render roads and to build up HD maps. Therefore, the vehicles deliver the data from the car to the cloud computers. Based on the collected data an HD map was created. This HD map enabled a completely autonomous prototype of a vehicle of the automotive manufacturer Daimler to drive through Germany (Seif and Hu, 2016).

One key factor that determines if a technological solution related to the field of cloud computing will be implemented by a manufacturing company is the question in which way and how much does the manufacturing company benefit from the implementation of cloud computing and related technological solutions?

Moreover, cloud computing for the use of data analytics gives manufacturing companies the possibility to access completely new areas of business activities. As the on-demand access to immense external computing capacities gives manufacturing companies the possibility to execute complex simulations without investing a massive amount of money into the local IT infrastructure (Lichtblau et al., 2015). Therefore, cloud computing and related technologies offer manufacturing companies the opportunity to reduce their costs significantly (Katz, 2017). Moreover, through the use of cloud computing the implementation costs for IT infrastructure can be reduced, as on-demand computing power can be bought from companies who offer cloud computing based services. An example therefore could be savings on the purchase and the instalment of an expensive server solution (Lichtblau et al., 2015).

Furthermore, cloud computing offers managers of companies the possibility to access and adjust single machines and the manufacturing process as a whole in cases where the physical access to the manufacturing equipment is limited (J. Lee et al., 2013). This advantage is strongly supported by the fact that cloud computing is generally extremely reliable (Katz, 2017). In addition, through the use of cloud computing and related technological solutions the flexibility within processes can be increased (Lichtblau et al., 2015). As capacities can be theoretically accessed from everywhere with a sufficient Internet connection and these capabilities generate costs only when they are used (Katz, 2017).

Moreover, cloud computing is also supporting other digital technologies like AI or Big Data for instance. As through the emerging of services related to the field of cloud computing an almost endless amount of computing capabilities is available to companies. For example cloud computing in combination with Big Data based solutions can help companies to find hidden patterns in large amounts of data (Scherk et al., 2017). Additionally, another benefit of cloud computing is that it supports the collaborative development of services and products between different companies (Katz, 2017).

Beside the benefits of cloud computing and the related technological solutions also the costs of implementation are a key factor which determine whether or not a manufacturing company implements cloud computing and related technologies.

Generally, the costs of implementation are fairly low in the field of cloud computing as the services which are related to cloud computing can be bought on-demand from companies that offer cloud computing as a service and are usually paid on a pay per use basis.(Lichtblau et al., 2015). Hence, it highly depends on the single companies and their projections if cloud computing and related technological solutions should be implemented within a manufacturing company. As, also the complexity of the tasks which are executed by technological solutions based on cloud computing determine how high the costs for cloud computing are. In addition, also the question to which extent the required technologies and infrastructure which are needed for the use of cloud computing and related technologies are influencing the costs of using technological solutions based on cloud computing. Moreover, it is projected that the costs for cloud computing as well as the costs for related technological solutions will decrease. This is caused by the technological development of cloud computing and the technological development of underlying technologies. In addition the price of these technologies is expected to fall in the future as the whole technological cluster data and connectivity is predominantly driven by an enormous reduction of costs (McKinsey Digital, 2015).

Another key factor which is expected to determine the adoption of cloud computing and related technologies is the question if and to which extent external business partners of manufacturing companies are already using cloud computing and related technologies. And are these companies willing to cooperate in the field of cloud computing. An example therefore would be the cooperation of two companies in the field of cloud computing when it comes to the joined development of products and services (Katz, 2017).

Another incremental aspect to consider when analyzing cloud computing and the related technological solutions, is the question of risk. As beside all the advantages and benefits which cloud computing and similar technologies offer to their users, these technologies also contain a certain amount of risk. Companies should take the aspect of risk into consideration before they implement these technologies. The risks related to the field of cloud computing are worth to be discussed in a critical way.

Contemporarily, research indicates that in particular the usage of cloud computing and related technological solutions is at the moment at a relatively low level in the manufacturing sector (Lichtblau et al., 2015). This can be also caused by the level of risk which manufacturing companies have to take when they implement technological solutions related to the field of cloud computing. A risk of cloud computing is its high dependence on fast broadband connection. If a sufficient broadband connection is not given then cloud computing and related services cannot meet their full potential (Katz, 2017). Moreover, another risk related to the field of cloud computing is the risk which is related to cyber-attacks. As through the use of cloud computing manufacturing companies are facing new security challenges. As when a huge amount of data of a manufacturing company is saved and process in the cloud the security of this data can be at stake (W. Hermann et al., 2017).

2.4.1.4. Blockchain

The terminology blockchain is becoming increasingly known. This development is especially caused by the fact that the term blockchain is closely related to the cryptocurrency Bitcoin. The

Bitcoin is the first cryptocurrency and was launched in 2009. The Bitcoin was partly a consequence of the 2008 world financial crisis. At this time people began to increasingly lose trust into central banks and national regulations. Already on October 31st in 2008 an anonymous programmer published a paper, using the pseudonym Satoshi Nakamoto. In this paper about "Bitcoin: A Peer-to-Peer Electronic Cash System," Satoshi Nakamoto described his new approach of a cryptocurrency called Bitcoin (Nakamoto, 2008; Oppitz and Tomsu, 2017). This paper built the fundament for the first cryptocurrency Bitcoin as well as for the new technology blockchain. As the Bitcoin is based on the blockchain technology (Oppitz and Tomsu, 2017). Nowadays, cryptocurrencies are becoming increasingly popular and have reached a market capitalization of over $288 billion. Bitcoins only account for over $115 billion of that market capitalization, which means that the Bitcoin has contemporarily a 40% market dominance over the whole cryptocurrency market (CoinCheckup.com, 2018).

But the blockchain can also be used in other fields than just for cryptocurrencies. The blockchain provides its users with the possibility to execute transactions in a safe and secure way via the Internet and without the involvement of third-parties (Oppitz and Tomsu, 2017). In general, the blockchain is defined as "a digital, distributed transaction ledger, with identical copies maintained on multiple computer systems controlled by different entities" (Schatsky and Muraskin, 2015). Before the development of the blockchain a centralized third party had to guarantee the correct execution of any transaction. Through the development of the blockchain the task of guaranteeing the correct execution of a transaction was handed over to the users of the blockchain (Oppitz and Tomsu, 2017). As long as over 50% of the CPU power is controlled by users who support the correct execution of transactions within the blockchain, the blockchain cannot be manipulated (Nakamoto, 2008). Additionally, the blockchain was built on the idea that all users of the blockchain are holding the ledger. This means that at any time all the ledgers consist of all blocks and transactions ever added to the blockchain (Oppitz and Tomsu, 2017). Additionally, everyone who is participating in a blockchain has the possibility to read the information in it. Moreover, a blockchain can only be updated if the majority of the participants approve that update. In addition, if information is added once to a blockchain this information cannot be deleted, this means that in a blockchain every accurate and verified information ever added to the blockchain is always recorded on the blockchain (Schatsky and Muraskin, 2015). After a transaction has been executed by a user of the blockchain with his personal private key, the data is distributed via the Internet in order to get confirmed by so-called miners. These miners are then verifying the transaction with the help of the public key of the user (Oppitz and Tomsu, 2017).

Nowadays, business opportunities based on blockchain related technologies become increasingly popular and a growing number of investors are attracted to these businesses. As already in 2015 a billion in capital has been invested by venture capitalists into over 120 start-ups which are related to technological solutions based on the blockchain (Schatsky and Muraskin, 2015). In addition, the World Economic Forum projects that until the year 2019 the banking sector only will invest over $400 million into digital technologies related to the blockchain (Oppitz and Tomsu, 2017).

Another important point for manufacturing companies to consider when it comes to blockchain based technologies is, how does the implementation of blockchain based technologies work in practice and what is changing in the company due to the implementation of these technologies.

Generally, blockchain related technologies can also be used in many fields beside cryptocurrencies; therefore, manufacturing companies should take a closer look at the blockchain and the related technologies. As the blockchain offers companies the possibility to move away from centralized approaches towards the distribution of ledgers, in cases where a contract has to be approved between different parties. Consequently, blockchain based solutions can be applied to almost any kind of agreement or value transfer for instance also for contracts between manufacturing companies and their suppliers (Oppitz and Tomsu, 2017). In general, there are two types of blockchains, private blockchains and public blockchains. For Bitcoins and other cryptocurrencies, a public blockchain is usually used. In a public blockchain everyone is able to join the blockchain. But it is also possible to create a private blockchain, where every entity who wants to join needs a permission to do so. Therefore, these technologies based on a private blockchain can be a promising tool for manufacturing companies (Schatsky and Muraskin, 2015).

Moreover, through the use of blockchain based technologies so-called smart contracts can be created. Smart contracts are agreements which are represented as software; these smart contacts can automatically activate certain actions if certain conditions are met. These conditions could be a payment which has been made or a payment which has been missed. For example, the customer only gets the product delivered when he made the payment. If not the delivery process is automatically stopped (Schatsky and Muraskin, 2015).

Furthermore, especially concerning the supply chain the blockchain and the related technological solutions are a promising tool for manufacturing companies. As the trend towards globalization goes hand in hand with an increasingly globalized supply chain. In these globalized supply chains, the amount of manufacturers, suppliers, logistic partners and retailers is likely to increase. This growth in participants is linked to an increasing amount of administrative processes which need to be executed. Handling these new emerging processes, the resulting flows of digital data between the different organizations and synchronizing this flow with the flow of goods is a key challenge for supply chain managers in the future. Therefore, the use of the blockchain and related technological solutions might be a promising tool for manufacturing companies as the flow of goods and data can be synchronized through the use of technological solutions based on the blockchain. The technology company IBM is already increasing the productivity of supply chains of over 600 organizations through the implementation of blockchain based technologies. Among these 600 companies are blue chips like Walmart and Maersk (Oppitz and Tomsu, 2017).

One key factor who determines if a technological solution related to the blockchain should be implemented by a manufacturing company is the question in which way and how much does the company benefit from the implementation of blockchain based technologies.

Generally, as the blockchain and the related technological solutions can be applied to almost any kind of process, these technologies have the potential to reduce costs, to increase efficiency and to simplify processes in almost any field where value and data is transformed between different entities (Oppitz and Tomsu, 2017).

Moreover, a key benefit of the blockchain is that blockchain based technologies are extremely save and reliable. As usually a high number of entities share a blockchain, the blockchain cannot be harmed through cyber-attacks that only target a single spot. Because when one entity fails to operate, the other entities will continue to maintain the blockchain. This means that the availability and reliability of the information within the blockchain is secured (Schatsky and Muraskin, 2015). Hence, through the implementation of blockchain based technologies reliability can be achieved without trusted intermediaries. As blockchain based technologies synchronize all data across the entire network. And every user of the network verifies the data of the others (Brody, 2017)

Another benefit of blockchain based technologies is the high level of transparency which blockchain based technologies offer to their users. As all transactions on the blockchain are visible for all users. This increases the comprehensibility and the trust among the users of a blockchain (Schatsky and Muraskin, 2015). Also, when it comes to the distribution of goods technological solutions based on the blockchain increase the transparency. Therefore, the blockchain among other technologies is a driver for long-term coalitions as well as for potential new emerging coalitions among organizations (Reiner et al., 2017).

Furthermore, the immutability of the blockchain is another key benefit of blockchain based technologies. As it is almost impossible to change the information within the blockchain without being detected by the other users of the blockchain. This fact reduces the possibility for cyber-attacks and fraud (Schatsky and Muraskin, 2015). This benefit goes hand in hand with the benefit of the traceability of information. As information can be found within minutes and even tracked back to its point of origin within the blockchain (Brody, 2017). In addition, this traceability of information is strongly connected to the irreversibility of the blockchain. As through the irreversibility of the blockchain the recorded transactions are more accurate and back-offices processes are easier to execute (Schatsky and Muraskin, 2015).

Additionally, blockchain based technologies have the full potential to reduce costs in general (Brody, 2017). Moreover, through the implementation of blockchain based solutions any kind of transaction costs can be reduced. In addition, also the use of so-called smart contracts can lower administrative costs significantly (Schatsky and Muraskin, 2015).

Another benefit to consider is that blockchain based technologies have the ability to manage and track resources. This leads to a better accuracy, more precise forecasts and the average inventory level can be reduced (Brody, 2017).

Beside the benefits of technological solution related to the blockchain also the costs of implementation are a key factor who determine if a manufacturing company implements blockchain based technologies.

Key aspects who determine the costs of implementation of blockchain related technologies are the complexity of a manufacturing process and the question to which extent the required compatible technologies and the infrastructure are already implemented into the production line and throughout the whole company.

Furthermore, blockchain based solutions are relying on a huge amount of computing power. Therefore, blockchain based solutions require a lot of energy. This can make these technologies relatively cost intensive (Schlatt et al., 2016). But as the whole cluster data and connectivity is predominantly driven by an enormous reduction of costs, also blockchain based technologies are expected to be increasingly energy efficient in the future (McKinsey Digital, 2015).

Another key factor which is expected to determine the adoption of blockchain based technologies is the question if and to which extent business partners of manufacturing companies have already implemented blockchain based solutions within their processes and if so, are these partners willing to cooperate in the field of blockchain based solutions.

In addition, an incremental aspect when analyzing digital technologies is the question of risk and which amount of risk is related to blockchain based technologies. As beside all the advantages and benefits which blockchain based technologies offer to their users, these technologies also contain a certain amount of risk. Manufacturing companies should take this aspect into consideration when they implement blockchain related technologies. These risks which are involved into the blockchain are worth to be discussed in a critical way.

A huge risk when it comes to blockchain based technologies is the interoperability of these blockchain based systems with other systems as this interoperability can be extremely limited. This implementation of blockchain based systems can cause technical difficulties between the existing systems and the newly implemented blockchain based system (Schlatt et al., 2016). Therefore, a connectivity gap between blockchain based systems and the non-blockchain based systems can emerge within a manufacturing company (McKinsey Digital, 2015).

Another big risk when it comes to the implementation of blockchain related technologies is the consumption of energy of blockchain based systems. This consumption can be extremely high and is contemporarily one of the biggest disadvantages of the blockchain (Schlatt et al., 2016)

Moreover, another risk which goes hand in hand with the advantages the blockchain offers. As through the transparency which blockchain based systems offer to their users, the anonymity of the single users of the blockchain cannot be guaranteed. This is caused by the fact that every information added to the blockchain is always recorded on the blockchain and can be seen by the participants of the blockchain. If then a blockchain identity of a person or institution is connected to the real identity of a person or institution, every action this person or institution ever made on the blockchain can be traced (Schatsky and Muraskin, 2015; Schlatt et al., 2016).

2.4.2. Analytics and Intelligence

The cluster analytics and intelligence includes technologies like Artificial Intelligence (AI), data analytics and Business Intelligence (BI). Especially in the last couple of years an impressive technological development has been accomplished within this cluster. While previously machines, robots and computers could only execute simple and repetitive duties this fundamentally changed in a time where technologies like AI and data analytics are able to perform increasingly complex tasks. Nowadays an almost endless amount of data combined with advanced statistical methods is available. These circumstances lay the fundament for the digitalization and automation of increasingly complex tasks like knowledge based activities and advanced data analytics (McKinsey Digital, 2015).

2.4.2.1. Artificial Intelligence – AI

Artificial Intelligence or short AI is not a completely new topic, which just emerged in the last couple of years, mankind has been facing this issue for decades. The connection of computers with human intelligence is since the beginning of electronical calculating a dream of experts within the field of IT science (Scherk et al., 2017).

Even though mankind has been making research for several decades in the field of Artificial Intelligence there has not been a universally accepted definition developed by practitioners of AI yet (Scherk et al., 2017). Therefore, there is no single approach towards AI available. Historically, there are four different approaches towards AI and each approach was followed by different people (Russell and Norvig, 2010). These four approaches are: systems that are thinking humanly, systems that are acting humanly, systems that are thinking rationally and systems that are acting rationally. Systems that are thinking humanly need to have for instance a cognitive architecture and neural networks. Systems that are acting humanly need to pass for example the Turing test. That means a computer needs to be capable of performing the following four abilities: natural language processing, automated reasoning, knowledge representation and machine learning. Systems that are thinking rationally are for instance optimization programs and logic solvers. Systems who are acting rationally are for example intelligent agents and robots who realize goals through perception, planning, cognitive learning, communication, decision-making and acting (National Science and Technology Council - Committee on Technology, 2016; Russell and Norvig, 2010).

The beginning of AI is dating back into the 1950s when Alan Turing asked in his work "Computing Machinery and Intelligence" the question if machines are capable of thinking. In this publication he also presented a test concerning this question, the so called "Turing Test" (Turing, 1950). In the following decades AI as field of science had some difficult times, the so-called AI winters, where the technological development in the field of AI was rarely emerging.

It took until 1990s when research in Artificial Intelligence was increasing significantly again. Research now began to focus more on sub-problems and the use of Artificial Intelligence for real problems like image recognition and medical diagnosis (National Science and Technology Council - Committee on Technology, 2016). In the year 1997 IBM's Deep Blue was the first chess computer who won a chess match against a world champion of chess, Garry Kasparov (Russel and Norvig, 2012). Further remarkable breakthroughs of AI technologies were the success of self-driving vehicles in the year 2000 at the DARPA Grand Challenge and the victory of IBM's question-answer computer Watson at a TV quiz show called "Jeopardy!" (National Science and Technology Council - Committee on Technology, 2016). Around the year 2010 the current wave of progress and popularity of AI technologies started. This wave was driven by three factors which were built upon each other. The first factor was the availability of a huge amount of data, better known as Big Data, this data was provided by multiple sources like governments, social media, commerce, e-commerce and businesses. These sources made the raw material for the second factor available. The second factor was significantly improved algorithms and machine learning approaches. These improvements were built on the third factor, the availability of more powerful computers (National Science and Technology Council - Committee on Technology, 2016; Scherk et al., 2017; Zhou et al., 2018). Moreover, companies nowadays invest a huge amount into the field of AI. It is estimated that already in the year 2016 companies invested between $26 and $39 billion US-Dollars into technological solutions related to the field of Artificial Intelligence (Bughin et al., 2017). Concerning the manufacturing sector, Artificial Intelligence is expected to be a driving force for the development of the manufacturing sector towards Industry 4.0. Moreover, Artificial Intelligence and the technologies related to the field of Artificial Intelligence are often described as intelligent manufacturing when speaking about AI solutions in the manufacturing sector (Zhou et al., 2018). Intelligent manufacturing is defined as "a smart approach to production where machines linked through the Internet assemble parts and adapt to new processes with minimal guidance from human operators" (Bughin et al., 2017).

The key questions for companies within the manufacturing sector when it comes to the implementation of Artificial Intelligence is how does the implementation of AI based solutions work in practice and what is changing in the manufacturing process due to the implementation of Artificial Intelligence? Before Artificial Intelligence can be directly implemented into the manufacturing process a foundation has to be built. The foundation before Artificial Intelligence can be completely implemented into a manufacturing process is the digitalization of the manufacturing process. A digitalized manufacturing process consists generally out of three key features. Firstly, solutions based on digital technologies are widely implemented and used. Secondly, digital information, simulations, modelling and the design are implemented to a big extent within a company. Thirdly, a digitalized production process is implemented (Zhou et al., 2018).

Traditionally, in the manufacturing sector the capital intensity is fairly high and the margins per product are usually relatively small. These two factors led historically to the fact that manufacturing moved to low cost countries. In this economic environment investments which were related to technologies like Artificial Intelligence or automation were usually not profitable. Therefore, the long-lasting absence of Artificial intelligence and other digital technologies in the manufacturing sector can be explained to a big extent. But rising wages in former low cost countries like China, Taiwan and Vietnam and the recent technological developments in fields like AI are contemporarily changing this relation and make investments in Artificial Intelligence for companies more attractive than ever (Dorfman, 2018).

Moreover, AI can be used in the field of manufacturing to perform tasks and to interact with humans. As AI based solutions are capable of perceiving information from their surroundings. This ability gives manufacturing robots the capability to interact with humans and to take even instructions from their human co-workers. Another very promising part of AI for the manufacturing sector could be the so-called machine vision. As high-tech cameras are way more sensitive than the eyes of a human, Artificial Intelligence has the possibility to generate a huge opportunity out of these high-quality pictures. For example, the Silicon Valley based start-up Landing.ai focuses with this technology on quality analysis of manufacturing goods. The use of machine vision, which is the combination of AI and high-tech cameras, enables a manufacturing company to find microscopic defects within their products. Therefore, an algorithm is used which analyses extremely small sample images. The recognition ability of this AI solution is way beyond the seeing abilities of a human being. Therefore the process of quality inspection can be taken to a whole new level (Dorfman, 2018).

Additionally, AI based solutions are not limited to this one example. As the areas in manufacturing where AI solutions can be implemented are almost endless (Dorfman 2018). Artificial Intelligence can be involved throughout the whole life-cycle of a product from the design of the product, over the production of the product and for services. Therefore Artificial Intelligence can be a valuable technology for companies (Zhou et al., 2018). The implementation and the use of Artificial Intelligence in the manufacturing sectors is most efficient and promising when difficult tasks have to be executed and complex decisions have to be made (Dorfman, 2018).

Consequently, Artificial Intelligence and the related technological solutions have the potential to disrupt whole end-to-end value chains in the manufacturing sector. Moreover, manufacturing companies are likely to adopt new designs for their production plants and to develop new forms of supply chains in future through the implementation of AI based solutions (Bughin et al., 2017)

A main factor who determines whether a technological solution related to the field of Artificial Intelligence should be implemented by a company or not is the question in which way does the company benefit from the implementation of technological solutions based on AI? Artificial Intelligence has the full potential of boosting the possibilities of robotics, as with AI based solutions robots can perform increasingly complex tasks and even work together with humans. But the benefits and possibilities of AI go far beyond the field of robotics, as AI solutions also have the potential to increase the efficiency of the supply chain, they can analyze demand in order to find new patterns and the adjustments can be immediately executed (Dorfman, 2018).

Moreover, AI gives manufacturing companies the opportunity to optimize processes within the whole company in real time (Bughin et al., 2017) Technological solutions related to AI have the capability to improve the product quality, the performance of a company and the service level by simultaneously reducing the amount of resources consumed (Zhou et al., 2018). Additionally, another benefit of AI based solutions is that they can decrease development cycles, decrease energy consumptions, increase the safety standards of processes by automating activities which involve a high level of risk for human workers, reducing the costs of inventory by planning supply and demand in an increasingly efficient way and increasing the overall revenue by sales analytics and optimization of pricing strategies. Furthermore, AI solutions give manufacturing companies the opportunity to integrate real time client and production feedback to improve the product design. A case studies of the consulting cooperation McKinsey & Company even showed that the implementation of AI has the potential to improve the accuracy of forecasts, to improve and to automate operations, create marketing and pricing strategies and to develop the consumer experience in a positive way (Bughin et al., 2017).

As demonstrated in the previous paragraph the areas in the manufacturing sector where AI solutions can be implemented and have the potential to create benefit for a manufacturing company are almost endless. As in theory AI can make almost everything, increasingly effective, better and cheaper (Dorfman, 2018).

But beside the benefits of Artificial Intelligence and the solutions which are related to the field of AI, also the costs of this technology determine if a company adopts AI based solutions or not. Artificial Intelligence is expected to be one of the big challenges which manufacturing companies are facing in the future, as this technology is developing in an astonishing speed (Stone et al., 2016). Beside the investment in the initial development of Artificial Intelligence itself, AI based solution also require investments in the storage of data, into processing technologies, into visualization technologies and into the implementation of sensors who collect the data. As the latest technological developments in the field of Artificial Intelligence were mainly driven by breakthroughs in other technological fields like cloud computing and Big Data (Zhou et al., 2018). Hence, the underlying technologies for AI are predominately from the cluster data and connectivity. This technological cluster is primarily driven by an enormous reduction of costs of technologies like cloud computing, Big Data and by decreasing costs of sensors. If this trend of decreasing costs continues, AI based solutions will become increasingly attractive for manufacturing companies in the future (McKinsey Digital, 2015; Stone et al., 2016).

In the case of some manufacturing companies, sufficient sensors and technologies might be already implemented into the production line but not used yet for solutions which are related to the field of AI. Of course, the costs of implementing AI technologies are extremely varying from company to company. Furthermore, these costs are highly dependable on the complexity of a production process and to which extent the required technologies and infrastructures are already implemented into the production line and throughout the whole company. Generally, bigger companies tend to profit more from the implementation of AI based solutions as the implementation of AI is usually a onetime fix-cost investment and afterwards higher returns are generated following the implementation of AI based solutions if the base of revenues and costs is higher (Bughin et al., 2017).

On the one hand, in the near future high costs for reliable mechanical devices are expected to limit the growth of AI based technologies in fields where expectations for productivity gains are limited. But on the other hand, in fields where high productivity gains are expected through the implementation of AI based solutions, Artificial Intelligence will become increasingly attractive (Stone et al., 2016). With decreasing costs and continuous technological development in the field of AI, the attractiveness of AI solutions is expected to increase for manufacturing companies in the future.

Another factor which is likely to determine the adoption of AI based solutions is the question if and to which extent business partners of manufacturing companies have already implemented similar solutions into their processes and operations and if these business partners are willing to share their data in order to improve the abilities of the AI based solutions.

One more significant aspect when analyzing Artificial Intelligence and the related technological solutions, is which risk is related to these technologies. As beside all the advantages and benefits which Artificial Intelligence and the related technological solutions offer, these technologies also contain a certain amount of risks. Businesses should take the aspect of risk into consideration before they implement technological solutions based on AI. These risks which are involved into the issue of Artificial Intelligence are worth to be discussed in a critical way.

Experts in the field of AI point out that a key factor which is hindering the development and implementation of AI based solutions is the fear of a loss in control and safety. Consequently, if even experts of AI do not have justified confidence that the implementation of Artificial Intelligence will not create unpredictable risks of negative consequences for the implementing company, its employees and for society in general then some argue that this technology should not be implemented in the first place (National Science and Technology Council - Committee on Technology, 2016). The IT giant Google already is tackling that issue and is thinking about a so-called kill switch. This kill switch should be implemented in technological solutions related to the field of AI and if this technology is not following the instructions or if it is not performing the given task then this kill switch gives someone the opportunity to stop the AI from doing their current action and turn it off. The challenging part of this emergency off button is that it has to be constructed in a way that the AI cannot bypass the kill switch (V. P. Andelfinger, 2017; Laurent Orseau and Armstrong, 2016).

As many other digital technologies, AI based solutions can be manipulated and used for espionage and sabotage by private persons, other companies or governments. These privacy and security risks can have extreme negative impacts on companies who implemented AI based solutions and are then the victim of a cyber-attack (National Science and Technology Council - Committee on Technology, 2016).

2.4.3. Human Machine Interaction – HMI

The cluster human machine interaction contains technologies like Augmented Reality (AR), authentication and customer interaction and profiling. The main foundation for HMI is the rapidly growing use of personal devices among consumers. Consequently, customers become increasingly used to interact with machines. Nowadays, touch interfaces are already widely implemented and relatively well-known to consumers. In addition, other technologies like gesture recognition, Virtual and Augmented Reality are becoming more and more popular. As an increasing number of average consumers is projected to use these technologies in their everyday life, it is expected that it will be easier for companies to implement HMI solutions in their workplaces in the future. Moreover, HMI also affects the physical interaction between humans and machines. With new technologies the physical proximity between machines and human is reduced and machines can support humans while they are executing their tasks (McKinsey Digital, 2015).

2.4.3.1. Virtual Reality – VR

Virtual Reality, also known as VR is today a widely known phenomenon as most people know VR from video games or flight simulators (Volker P. Andelfinger et al., 2015). The basic idea of Virtual Reality is a 3D environment synthesized by computers, therefore VR is defined as "a computer-simulated environment with and within which people can interact" (Riva, 2006). Hence, Virtual Reality is a computer based technology which simulates either a real or a fictional environment. Additionally, the physical presence of the user is also simulated in that environment. Moreover, VR allows the users to interact with each other in the environment created by VR. Virtual Reality is also capable of generating virtual experience of touch, sight, sound and smell (Oppitz and Tomsu, 2017).

For VR a 3D environment is synthesized by a computer through numerical data. Therefore, technological solutions are used to create a preferably high variety of senses. The aim of VR is it to enable the user to experience an environment which is as realistic as possible. This environment, which is generated by computing power can be either a model of the real world or an environment which is based on pure fiction and is not existing in the real world (Riva, 2006). Furthermore, Virtual Reality is expected to increasingly enter the living rooms of people all over the globe. This would make people in general more familiar with the technology and consequently it would be easier to train employees in the field of Virtual Reality, as these people would be already familiar with that technology (Stone et al., 2016). Additionally, nowadays VR has not only a major impact on the video gaming sector, also in other industries like automotive and aerospace the popularity of VR based solutions is growing and also for the manufacturing sector VR offers some promising perspectives (Nee and Ong, 2013; Oppitz and Tomsu, 2017).

Especially when regarding the example of a flight simulator, it becomes most obvious that the simulation should be as realistic as possible. Therefore, the goal is to reach as many senses as possible through the simulation. The combination of many different senses makes Virtual Reality more realistic and gives the user a better user experience. These high requirements are the main reason why high-tech flight simulators, which are used for the training of pilots, are extremely expensive systems. In this case the simulations require a lot of quality in order to match the different senses with another. If the synchronization of the different senses is not achieved than the so-called motion sickness can occur. Nevertheless, Virtual Reality is becoming increasingly popular among players of video games. Developments like the Oculus Rift, Samsung VR, or the HTC Vive enable private customers to use VR solutions. But the use of VR based solutions requires a enormous amount of computing power and some personal computers with low or medium computing power cannot reach these requirements (Hänisch, 2017). In addition, todays VR based solutions are usually relatively big and have the size of approximately half a football. But the trend in the field of VR goes towards increasingly smaller VR devices, maybe in future even implants and by closing the eyes one can enter a virtual world. The future VR solutions could even create a virtual illusion which is almost perfect (Oppitz and Tomsu, 2017). Moreover, Virtual Reality systems among others are expected to be a significant part of the implementation strategies of digital technologies in the manufacturing sector in the future (Kumar, 2017).

Another important point for companies within the manufacturing sector to consider when it comes to VR based solutions is how does the implementation of Virtual Reality based technologies work in practice and what is changing in the manufacturing process due to the implementation of these technologies.

In general, not only airlines, video game producers and their consumers can profit from the latest developments in the field of Virtual Reality, also manufacturing companies see enormous potential in the field of VR. As companies like Boeing or BMW are already using VR based solutions in order to accelerate and to simplify the developments of new models (Hänisch, 2017).

Moreover, through the use of VR based technologies the developments of technologies like cyber physic systems, also known as CPS in the manufacturing sector can be accelerated. The use of Virtual Reality in a manufacturing company gives the company the possibility to create a virtual production process in which for instance a cyber physical production system can be completely simulated and explored in an interactive way (Bauernhansl et al., 2014). As whole manufacturing processes can be simulated and displayed via VR based solutions, this enables employees of companies to experience their new workplace before it is even built. Moreover, this would give employees the possibility to bring in their thoughts at an early stage so that possible problems are detected much early then without the use of VR based solutions (Buchholz et al., 2017).

Furthermore, VR based solutions can be implemented in order to create the design of a product virtually, this gives designers in a manufacturing company the possibility to interact with other designers and employees in an intuitive and interactive way. Especially, when it comes to the visualization of the product (Nee and Ong, 2013).

In addition, Virtual Reality can be used to simulate critical simulations in a manufacturing company and train the workers how to react when certain events occur. Therefore, VR can increase the level of skills of the workforce within a company and consequently the ability of workers to react appropriately when certain events occur is likely to increase. In the long run this could have a positive effect on the overall company (Stock and Seliger, 2016).

Another advantage of VR is that through the simulation of whole production processes via Virtual Reality whole teams can work together on the same project even though they are separated through distance and time. This gives companies the opportunity to work together with business partners with which it was not practical to work together before due to the separation in distance and time (Buchholz et al., 2017).

One key factor who determines whether or not a technological solution related to the field of Virtual Reality should be implemented by a manufacturing company is the question in which way and how much does the company benefit from the implementation of technologies based on Virtual Reality?

Company can easily profit from the superior visualization ability of VR related technologies, as almost any kind of information can be better demonstrated to employees and business partners through the use of VR based solutions (Brettel et al., 2014). Another benefit of VR based solutions is that the separation in distance and time between business partners can be bridged in a more effective way (Buchholz et al., 2017). Moreover, VR enables manufacturing companies to analyze, adjust and optimize processes virtually before these processes are even implemented in reality (Bauernhansl et al., 2014; Buchholz et al., 2017). Especially, when it comes to mechanical assembly Virtual Reality allows the users to fully enter the virtual environment and gives them the ability to gain new knowledge. This leads to the fact that many VR based solutions have been successfully implemented to assist manufacturing process activities (Nee and Ong, 2013). Additionally, the level of skill of employees within a manufacturing company can be improved through simulations of critical events (Stock and Seliger, 2016).

Beside the benefits of technological solution related to VR also the costs of implementation are a key factor which determines whether or not a company implements technologies related to the field of Virtual Reality. In general, the costs of implementing technologies related to the field of Virtual Reality are extremely varying between different companies. Furthermore, these costs are highly dependable where and to which extent VR will be implemented within the company. Additionally, also the complexity of a production process and to which extent the required technologies and infrastructure are already implemented into the production line and throughout the whole company are influencing the costs implementation. Furthermore, VR based solutions are relying on a huge amount of computing power as VR environments are extremely complex to simulate. Therefore, the cost of implementing VR into a manufacturing company can be fairly high due to expenses into high computing capabilities. Consequently more computing capabilities will also increase the energy consumption of a manufacturing company (Nee and Ong, 2013). Another key factor which is expected to determine the adoption of VR based technologies is the question if and to which extent business partners of manufacturing companies have already implemented similar technological solutions within their processes and if so, are these companies willing to cooperate in the field of Virtual Reality.

Another significant aspect when analyzing Virtual Reality is which risk is related to that technology. As beside all the advantages and benefits which Virtual Reality and the related technological solutions offer, these technologies are also related to a certain amount of risk. Companies should take this aspect into consideration before they implement these technologies. These risks which are involved into the issue of Virtual Reality are worth to be discussed in a critical way. A huge risk when it comes to the implementation of Virtual Reality is the question if the potential benefits outweigh the costs. As an investment in VR is usually relatively expensive and if the full potential of VR is not used the benefits of VR can be relatively small.

Additionally, as Virtual Reality is still a newly emerging technology and not perfectly developed yet. It is possible that through the use of VR solutions the so-called motion sickness can occur if the synchronization of the different senses is not handled perfectly (Hänisch, 2017). Another big limitation for VR when it comes to its implementation into manufacturing processes is that contemporarily it is very complex to exactly model the actual environment as well as the manufacturing process who is located within that working environment. On the one hand, this is caused by the fact that VR based technologies require a lot of real time computing capabilities to generate these complex simulations. And on the other hand, new advanced approaches who are tackling that challenge in particular are not perfectly developed yet, but they are expected to become reality in future with an increasing technological development concerning Virtual Reality (Nee and Ong, 2013). Furthermore, another risk which the implementation of VR based technologies brings with it is the risk that partner companies are not willing to use VR or they just do not have the capabilities for it. Therefor the benefits of VR would be limited (Buchholz et al., 2017). Moreover, concerning the implementation of VR based manufacturing process simulations, any derivation of the simulated manufacturing environment to the real existing manufacturing process can influence the actual benefits of implementing VR based solutions within a manufacturing company in a negative way (Nee and Ong, 2013).

2.4.3.2. Augmented Reality – AR

Even more promising than Virtual Reality is for the practical use in manufacturing companies is Augmented Reality also known as AR. AR does not only show the simulated environment, AR integrates a simulated environment into the real world (Hänisch, 2017). Since smartphones and tablets have been established on the market for consumer electronics also the topic AR reached a new dimension (Hänisch, 2017). Technological devices related to the field of AR are increasingly used (McKinsey Digital, 2015). As almost all smartphones and tablets are equipped with cameras, which have the ability of capturing the real world and add additional information, which overlays the real world environment on the display (Bauernhansl et al., 2014). One of the first contact many people had with Augmented Reality was when the AR based game Pokémon Go made it to the top of the mobile gaming download charts in 2016 (Rauschnabel et al., 2017). Before that people new this digital technology mostly from live broadcasts of football games, where for instance the distance of freekicks to the goal is usually integrated into the live broadcast via AR based solutions (Hänisch, 2017). Another famous approach of bringing Augmented Reality to a wider audience is Googles AR based solution Google Glass (Hänisch, 2017; Stoltz et al., 2017).

But beside the opportunities AR based solutions offer in the field of gaming and consumer electronics, AR solutions can be also a very promising tool for manufacturing companies (Hänisch, 2017). Moreover, Augmented Reality is a real innovation and a relatively new digital technology to the manufacturing sector, unlike other digital technologies like Big Data. As a consequence, an extremely significant point for these companies to consider, when it comes to the implementation of Augmented Reality and related technologies, is how does the implementation of these technologies work in practice and what is changing in the manufacturing process due to the implementation of AR based technologies (McKinsey Digital, 2015)?

Augmented Reality increasingly gains the interest of companies when it comes to the support of human workers. As AR based solutions can display information while human workers execute their tasks. The information is shown to the employee while the employee is executing the task with two free hands (Bauernhansl et al., 2014). Therefore, AR based solution have the potential of supporting many processes in manufacturing companies (Hänisch, 2017). Moreover, AR based solutions can be used by a manufacturing company in form of AR glasses. This AR based solution has the ability to display relevant information instantly into the field of view of an employee. In addition, AR glasses can show an employee in a manufacturing plant multiple information about processes in real time as well as plans for maintenance and repair work (Bauernhansl et al., 2014).

A practical example for a AR based solution would be KiSoft Vision, which was developed by the Knapp AG, who is located in the logistics sector. KiSoft Vision is a technological solution based on AR and is worn like a headset by an employee. KiSoft Vision has been developed in order to improve the process of picking goods in a warehouse. Wearing KiSoft Vision the employee is seeing in his field of vision virtual information, this information is relevant for the process of picking goods. This virtual information is partially place over the real view of the employee. KiSoft Vision gives employees the ability to locate goods more precisely and much quicker. Moreover, this AR based solution can also guide the employee to a building and make recommendations where certain goods can be stored. When wearing KiSoft Vision the employee has two free hands since the use of paper is no longer needed. In addition, ID numbers and serial numbers can be captured by the camera which is integrated within this AR based solution. This technology also enables the tracking of the stock in real time. The two main benefits of technologies like KiSoft Vision are the reduction of errors by around 40% and the decrease in time spend on the training for new employed workers (McKinsey Digital, 2015).

Additionally, support teams from outside the manufacturing plant can support an employee in the manufacturing plant in real time. As through the camera which is implemented into the AR glasses the support team has the possibility to see what the employee in the manufacturing plant is seeing (Bauernhansl et al., 2014). An example would be the maintenance of a complicated industrial system which could be supervised by a support team via AR based solutions (Hänisch, 2017). Consequently, the support team can guide the employee in the plant and give him the right instructions based on what the support team sees through the AR based solution (Bauernhansl et al., 2014). Moreover, the support team is also able to display information like construction plans on the AR glasses of the employee, in order to give the employee additional information (Hänisch, 2017). Furthermore, Augmented Reality can be also implemented into fork-lift trucks or other vehicles in order to guide the driver via AR based solutions which are located in the windshield of the vehicle (Bauernhansl et al., 2014)

One key factor who determines whether or not a technological solution related to the field of Augmented Reality will be implemented by a manufacturing company is the question in which way and how much does the company benefit from the implementation of these AR based solutions?

With the help of Augment Reality and related technological solutions the latest data about the company can be highlighted in real time. Significant data could be the efficiency of processes, quality management and the planning of operations. All these information can be displayed to the user of AR based solutions while the user is executing other tasks (Geissbauer et al., 2016). Additionally, as the example of KiSoft Vision showed, AR based solutions have the potential to increase the efficiency in the warehouse, to allow companies to track their stock in real time, to reduce errors by around 40% and to decrease the training time needed to train new employees (McKinsey Digital, 2015). Furthermore, AR based solutions have the ability to reduce costs (Geissbauer et al., 2016). Especially in the field of maintenance and repairs technological solutions like AR glasses have the potential to decrease costs and the time which is spend on maintenance and repair tasks. This could lead to a decrease of costs as faster maintenance and repair processes are going hand in hand with less stops in the manufacturing process (Bauernhansl et al., 2014). Moreover, AR based solutions have the ability to increase the efficiency of processes within a company (Geissbauer et al., 2016). Another benefit of AR based solutions, is that with AR untrained employees can solve complicated problems in a manufacturing plant when they are supervised by a support team in real time via AR based solutions (Bauernhansl et al., 2014)

Beside the benefits of Augmented Reality and the related technological solutions also the costs of implementation are a key factor which determines whether or not a company implements technologies related to the field of Virtual Reality.

Generally, the costs of implementation are highly dependent on the complexity of a manufacturing company and to which extent AR based solutions and the required infrastructure are already implemented throughout the whole. Another key factor which is expected to determine the adoption of Augmented Reality is the question if and to which extent business partners of manufacturing companies have already implemented similar technological solutions within their processes and if so, are these companies willing to cooperate in the field of Augmented Reality. If the business partners of the companies which is planning to implement AR based solutions are not willing to cooperate within that field, the expected benefits which the implementation of AR based solutions bring with it could be extremely limited. Additionally, the cost to implement AR based solutions are currently still relatively high (Bauernhansl et al., 2014).

Another incremental aspect when analyzing Augmented Reality is the question of risk and which risk is related to AR and AR based solutions. As beside all the advantages and benefits which this technological solution offers, AR and the related technological solutions contain also a certain amount of risk. Companies should take this risk into consideration before they implement AR based solutions. This risk should be discussed in a critical way.

One risk of Augmented Reality is that the employees will not use the AR based technology because it is perceived has hard to use. In addition, AR based solutions could limit the ability of employees to move and employees could feel monitored if they wear for instance AR glasses with an integrated camera (Bauernhansl et al., 2014). Moreover, another risk which the implementation of AR based solution as well as the implementation of many other digital technologies brings with it is the risk of being the target of industrial sabotage and industrial espionage. Especially AR based technologies could be relatively easily become the target of hackers as this technological solution has to be connected to the Internet in order to reach the full potential of this technology, like getting assistance from a support team outside the current manufacturing site (McKinsey Digital, 2015).

2.4.4. Digital to physical conversion

The cluster digital to physical conversion includes technologies like cyber-physical-systems (CPS) and 3D-printing. This cluster is primarily driven by declining costs, an increasing amount of various materials and highly developed precision and quality. For example, previously 3D-printing was only usable for polymers and metals. At the present time, 3D-printing can be executed with a wide-ranging set of materials, which includes bio cells, sugar and glass. Simultaneously with the growing set of available materials the size of 3D-printers also grew, compared to the 1990s 3D-printers can be today up to ten times bigger than back then (McKinsey Digital, 2015).

2.4.4.1. Cyber Physic Systems – CPS

Cyber physic systems, also known as CPS are linking the physical world and the virtual world with another. This is achieved by communication via a data infrastructure which is better known as the Internet of Things or simply IoT. Moreover, CPS make it possible to create a virtual model of a real manufacturing process. Additionally, CPS have the ability to analyze all data streams which are produced by sensors or other IT systems and map how they are interrelated (Lichtblau et al., 2015). CPS are defined as the "integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" (E. A. Lee, 2008). CPS have an enormous potential as the versatility of CPS is almost endless. Example for CPS are intelligent cars, intelligent traffic control, robotic surgery, smart production equipment and smart buildings (National Institute of Standards and Technology, 2013).

CPS enables that machinery, people, products and resources in a so called smart factory can communicate which each other. Consequently, a smart factory highly relies on CPS, as they are linking the physical with the virtual world (Lichtblau et al., 2015). In this manufacturing environment of the twenty-first century, sensors, processors and devices which are capable of communicating with each other are implemented and collect and distribute real time data about raw material, products, machines and the manufacturing process. Therefore, CPS build the foundation of the communication between machines and their human operators, machines and machines and products and machines. Additionally, machines are developing towards a self-controlled execution of certain tasks. This process of interaction between products and machines via networks is becoming increasingly smart (Feng and George Shanthikumar, 2017). Hence, CPS bridge the gap between physical processes, computing and networks (Khaitan and McCalley, 2015).

Generally, CPS are developed in three phases. The first phase of the development of CPS consists of identification technologies. These identification technologies enable the exclusive identification of machines, raw materials and products. An example for an identification technology is a RFID tag. The second phase of the development of CPS consisted of actuators and sensors which functions are usually limited. The third phase of the development of CPS consists of CPS which have the ability to store and analyze collected data. Moreover, this third generation of CPS is equipped with several actuators and sensors which are capable of communicating within a network (Bauernhansl et al., 2014; M. Hermann et al., 2016).

Moreover, CPS are breaking the hierarchical communication boundaries and transform the classical automation pyramid into a network as information flows freely between the different levels. This development is expected to be the foundation of an autonomous production system in which machines and products learn from each other through the interaction via networks (Feng and George Shanthikumar, 2017).

An incremental aspect for companies within the manufacturing sector to consider when it comes to the implementation of CPS and the related technological solutions is how does the implementation of CPS work in practice and what is changing in the manufacturing process due to the implementation of these technologies.

The implementation of CPS brings several significant changes into the manufacturing process. In the manufacturing plant of the future where CPS are implemented to a high extent, the degree of automatization and flexibility is extremely high. This manufacturing plant is consisting of various CPS who are interconnected and control the manufacturing process to a large extent by themselves. Additionally, in a manufacturing plant like this the products are expected to have, already during the manufacturing process, integrated systems. These systems then have the possibility to interact with the manufacturing process. This enables manufacturers to have a high degree of efficiency and effectiveness when it comes to the personalization and the individualization within the production process. Therefore products can be even modified by the customer right before they are actually produced (Broy, 2010).

One key factor who determines whether or not a CPS will be implemented by a manufacturing company is the question in which way and how much does the manufacturing company benefit from the implementation of CPS?

In general, CPS are extremely promising as trough the implementation of CPS and other digital technologies, which are related to Industry 4.0 companies are expected to increase their productivity by 30% (Heng, 2014). This enormous gain in productivity is caused by several factors. One huge factor which strongly supports the implementation of CPS is that CPS enable manufacturing companies to produce more efficiently and increasingly flexible (Broy, 2010; J. Lee et al., 2015). In addition, through the communication between CPS valuable information can be gained. This new information provides a higher level of transparency which can lead to significant improvements within the manufacturing process and within the whole company (Bechtold et al., 2014). Moreover, the implementation of CPS enables a company to decentralize their decisions as people and objects are interconnected and information can be transferred into and out of a manufacturing plant (M. Hermann et al., 2016; E. A. Lee, 2008). Further benefits of CPS are that they are capable of providing a real time quality control, they can decrease the time of production, CPS can lower the amount of resources used within the production process and they can decrease the overall costs of production (Majstorovic et al., 2015).

But beside the impressive benefits which CPS offer also the costs of implementation are a key factor which determines whether or not a company implements technological solutions related to the field of CPS.

Generally, CPS are expected to create a huge amount of data, this cost factor has to be taken into consideration by companies if they think about implementing CPS. As this data created by CPS has to be processed and stored. Additionally, the results of the analyzed data should be ideally available anywhere at any time in real time. This requires investments in cloud based technologies (Bechtold et al., 2014). Hence, the underlying technologies for CPS are predominately from the cluster data and connectivity. Furthermore, the cluster data and connectivity contains technologies like Big Data, the Internet of Things (IoT), blockchain based technologies and cloud computing among others. This cluster is predominantly driven by an enormous reduction of costs. Sensors, hardware, digital storage and the transmission of data are just a few examples of fields where an enormous reduction in costs enables great chances for companies who use and know how to use these technologies in an effective way (McKinsey

Digital, 2015). The decreasing costs of sensors, networks and other technologies are a direct result of the current technological developments, through which the availability of these technologies increased whereas at the same time the price of them decreased (J. Lee et al., 2013; Shi et al., 2011).

Additionally, another aspect which has a significant impact on the answer of the question whether or not a company implements CPS is the complexity of a production process and to which extent the required technologies and infrastructure are already implemented into the production line and throughout the whole company. These are all factors which influence the costs of implementation.

One more key factor which determines the adoption of CPS is the question if and to which extent business partners of manufacturing companies have already implemented similar technological solutions within their processes and if so, are these business partner willing to cooperate in the field of CPS.

Another incremental aspect when analyzing digital technologies is the question of risk and which risk is related to that specific technology. As beside all the advantages and benefits which CPS offer, the implementation of CPS also contains a certain amount of risk. Companies should take this aspect into consideration before they implement CPS. Therefore, the risks which are involved into CPS are worth to be discussed in a critical way.

As CPS consist of several software and hardware components, which are interacting with each other, these components or the CPS as a whole could be the aim of a cyber-attack. Therefore, hardware and software security are a challenging issue when it comes to CPS (Monostori et al., 2016). Additionally, as the field of CPS is fairly new to the manufacturing sector the issue of cyber-security in relation with CPS has not been researched in detail yet (Kumar, 2017). Another factor of risk when it comes to CPS is that even when adjustments of minor software or hardware parts of a CPS are done, negative effects on the system as a whole can occur as a unintended result of the adjustments (E. A. Lee, 2008).

2.4.4.2. 3D-printing

Nowadays, 3D-pinters are widely known, mainly for their use when it comes to the modelling of prototypes and for the creation of simple products. But the potential use of 3D-printers and related technological solutions goes for beyond the field of product design and the production of simple goods (Buchholz et al., 2017; Katz, 2017). As it is currently expected that 3D-printing and the related technological solutions are still in their beginning stage of their overall development (Katz, 2017). Moreover, technological solutions related to the field of 3D-printing are projected to be increasingly used in value creating processes in the future (Hagel III et al., 2015). Generally, 3D-printing is also known as additive manufacturing and defined as "the production of three-dimensional objects directly from virtual models" (Bechtold et al., 2014). Additionally, the technological developments in the field of 3D-printing are impressive as this technology was several years ago just applicable for materials like metals and polymers, nowadays materials like bio cells, glass, cement and sugar can be used in order to print out objects with an 3D-printer. Simultaneously to the enormous extension in materials which can be used for 3D-printing also the maximum size of a 3D-printer increased significantly. As nowadays 3D-pinters are up to ten times larger than they used to be in the 1990s (McKinsey Digital, 2015).

Another key aspect for manufacturing companies to consider when it comes to 3D-printing and the related technological solutions is how does the implementation of 3D-printing work in practice and what is changing in the process of manufacturing due to the implementation of 3D-printing and related technologies.

Through the possibilities which the process of digitalization and the development towards Industry 4.0 offer to manufacturing companies, processes which were previously incremental for whole business models may become obsolete in a couple of years. The production of goods via 3D-printers could be an example for that development. The technological progress in the field of 3D-printing is a key driver for the change towards the decentralization of production (Lueghammer et al., 2015). Especially 3D-printers have the full potential to disrupt the field of production and consequently also the field of logistics in a fundamental way. As through the use of 3D-printers, production itself can be decentralized and products can be produced directly where and when they are needed (Buchholz et al., 2017).

An example for an industry where 3D-printers are likely to be the state of the art relatively soon is the sector of dental technology. In this sector 3D-printers have the potential to execute the work in future, which dental technicians do nowadays (Löhr, 2018). Moreover, the IT giant Amazon entered the market for 3D-printing as a provider, by launching a service that focuses on mass 3D-printing. It is expected that many companies like Amazon will enter the field of manufacturing without actually setting up physical manufacturing capabilities. Additionally, they are expected to outsource this part and create value through providing agile collaboration networks (Bechtold et al., 2014). However, not only IT giants are about to lever the advantages of 3D-printing, also the sportswear manufacturer Nike has introduced a so-called Advanced Product Creation Centre in his headquarter in the United States, in order to explore emerging manufacturing methods like 3D-printing. Furthermore, technologies related to the field of 3D-printing have been already used by Nike to customize shoes for several athletes (The Economist, 2017).

In addition, start-ups like Shapeways, a provider of 3D-printing marketplaces and other 3D-printing services is an example for how the manufacturing market can be entered successfully by using digital technologies like 3D-printing (Bechtold et al., 2014). Another example for how advanced the field of 3D-printing already is, is the automotive company Local Motors which manufactures vehicles almost completely through the use of 3D-printing. Local Motors managed it to reduce the development cycle to only one year. Whereas the average development cycle in the automotive industry is contemporarily between six and seven years. Through this reduction of the development cycle R&D expeditor can be massively reduced (McKinsey Digital, 2015; Werner, 2015).

Another key factor who determines whether or not technological solution related to the field of 3D-printing should be implemented by a manufacturing company is the question in which way and how much does the manufacturing company benefit from the implementation of the 3D-printing and the related technologies.

Furthermore, the highly decentralization of production is one of the key benefits of 3D-printing and the related technological solutions. As a digital model could just be send to a 3D-printing site which is located near to the final customer. This would eliminate several production steps, reduce transportation costs and would even make the warehouse obsolete. Consequently, 3D-printing has the full potential to change how, where and through whom goods are produced in the future (Bechtold et al., 2014). This decentralization of production would lead to a massive reduction of classical production transports, whereas at the same time new transports for printing materials could be created (Lueghammer et al., 2015).

Moreover, 3D-printing can be a key success factor when it comes to increase the efficiency of the supply chain. As through decentralization operating cost as well as the lead time can be reduced. In addition, the decentralization of production through 3D-printing gives companies the possibility to react quicker and more effectively to changes in local market demand

(Bechtold et al., 2014). Consequently, also the response time of the supply chain can be reduced through the implementation of 3D-printing and related technological solutions (Katz, 2017).

Additionally, 3D-printing allows companies to create prototypes faster than ever. This could accelerate the development of new products massively (Bechtold et al., 2014). Another point to consider is that 3D-printing can reduce the time a new product needs to enter the market. Hence, the implementation of 3D-printing and related technologies could give companies an so-called early-mover advantage and consequently the revenues of these companies could increase (McKinsey Digital, 2015).

Furthermore, 3D-printing gives companies the possibility to move production closer to the final customer. This development goes hand in hand with a higher level of customization and individualization of products (Geissbauer et al., 2016). Consequently, 3D-printing and the related technologies are also expected to have an positive impact on customer satisfaction, due to the decrease of delivery time and the positive aspects of customization and individualization (Bechtold et al., 2014).

Beside the benefits of technological solution related to the field of 3D-printing also the costs of implementation are a key factor that determines whether or not a company should implement technological solutions based on 3D-printing. Additionally, also the complexity of a manufacturing process and to which extent 3D-printing and the needed infrastructure is already implemented throughout the whole company are influencing the costs of implementation. As the cost of implementing 3D-printing into a manufacturing company can be relatively high due to investments in the infrastructure and investments in the digital design of a product.

From a managerial point of view the use of 3D-printer is highly relate to the profitability of this technological solution. Therefore, companies have to take into consideration which effects the implementation of technological solutions related to the field of 3D-printers have on processes like the manufacturing process and the distribution process of a company, as 3D-printers have the potential to disrupt the structure of these processes in a fundamental way (Lueghammer et al., 2015). However, in the end manufacturing companies have to decide whether a part should be produced in a factory and shipped via traditional transportation methods to the customer or if this part should be printed out directly where the part is needed via a 3D-printer. This decision is mainly based on the costs which are caused by 3D-printing and the related technological solutions (Bauernhansl et al., 2014).

Moreover, manufacturing companies also have to ask themselves the question if their products can be even produced with the state of the art 3D-printing technologies or are traditional manufacturing methods still superior in that particular fields. Especially, when it comes to the cost structure the costs of producing products with a 3D-printer or related technological solutions are contemporarily still relatively high compared to common ways of manufacturing. One main reason for these relatively high costs is that the production process with 3D-printers is at the moment relatively slow. Additionally, the variety of materials which can be used for 3D-printing are currently limited. Furthermore, the price for these printing materials is still relatively high (Bechtold et al., 2014). But the trend is currently in favor of decreasing costs in the field of 3D-printing, as the prices have been dropping within the last couple of years (Hagel III et al., 2015). Moreover, it is expected that through the technological development in the field of 3D-printing the disadvantages of this technology like the high material costs, the slow production speed and the limited variety of materials will be reduced in future (Bechtold et al., 2014).

Another key factor which is expected to determine the adoption of 3D-printing and the related digital technologies is the question whether and to which extent business partners of manufacturing companies have already implemented similar technological solutions within their company and if so, are these business partners willing to cooperate in the field of 3D-printing. This cooperation is highly dependable on the willingness of the potential business partners to share their digital 3D-printing models.

Another incremental aspect when analyzing digital technologies is the aspect of risk. And the question which risk is related to the field of 3D-printing, as beside all the advantages and benefits which 3D-printing and the related technological solutions offer, these technologies also contain a certain amount of risk. Companies should take the aspect of risk into consideration before they implement these technologies. These risks which are involved into the issue of 3D-printing are worth to be discussed in a critical way.

An relatively often mentioned example for the risk which is related to 3D-printing, is the risk that 3D-printers can produce products other than mechanical parts who are needed in a manufacturing line or plastic cases for smartphones. 3D-printers can also be used for the production of dangerous goods like guns, as this and similar goods can be produced with the support of digital production plans downloaded via the Internet (Hänisch, 2017; New Scientist, 2014).

Moreover, another critical aspect to consider is that, as 3D-printers and related technological solutions are increasingly used in the field of manufacturing, it becomes more and more possible that these technologies get into the focus of cyber-attacks. An example for a cyber-attack on a 3D-printer could be the manipulation of digital production plans which are used for the manufacturing of parts. If these parts would then be used in products like jet engines, the life of humans could be endangered (Yampolskiy et al., 2016).

Chapter 3

3. Research Objectives and Methodology

3.1. Methodology

In the previous chapters the theoretical background of this thesis, “Digitalization in the manufacturing sector: Current state, impact on performance and determinants of adoption”, has been discussed. In the following chapter the research methodology is presented. This methodology is used in order to find reliable answers to the four research questions. Moreover, in order to ensure a reasonable connection between the theoretical and the empirical part of this thesis, a brief overview about the scientific contribution is given in the section 7.1.. Section 7.2. reveals the four research questions to the reader. The section 7.3. is dedicated to the research approach. This aim is accomplished by describing the methods which are used to execute the practical part of this thesis. In the section 7.4. the research design is presented to the reader. Therefore, this subchapter shows the reader how the data has been collected, processed and analyzed.

3.1.1 Scientific contribution

The aim of the previous literature review was it to present an overview about the topics: Industry 4.0, digitalization, digital intensity of the manufacturing sector, the four clusters of disruptive technologies and the underlying digital technologies. Whereas the main digital technologies where analyzed in detail, as examples for their implementation, their benefits, the costs these technologies cause and the risks the implementation of these technologies involve, were offered to the reader.

In order to collect appropriate information to create the literature review and to build the foundation for answering the four research questions, several online databases were mainly used. The most used data bases within this thesis were sciencedirect.com, scholar.google.at, emeraldinsight.com and link.springer.com. The search for sources with suitable information was challenging as the topics digitalization and Industry 4.0 are fast-evolving topics and new insights are constantly created. Therefore, it is essential to find up-to-date sources which are reliable. Nevertheless, it became relatively soon clear that finding literature, which offers numbers and figures, that show the exact benefits and costs of digital technologies as well as information about the concrete risks companies face, when implementing certain digital technologies, will become challenging. Especially, finding up-to-date examples of the implementation of digital technologies into manufacturing companies, developed into the toughest issue. As this kind of information is extremely sensible for manufacturing companies, due to the risk, that this information could give competitors any kind of competitive advantage.

However, the search for literature was conducted with keywords like "digitalization", "Industry 4.0", "manufacturing", "Big Data", "Artificial Intelligence" and many others. These keywords were combined with words like "implementation", "benefit", "cost" or "risk". Through the use of this approach a sufficient amount of information could be gained in order to complete the literature review. Overall, the literature review of this thesis consists out of over 100 different sources. Thereby, research papers built the backbone of this thesis. Followed by books, reports, journals and websites. All the collected literature was compared in order to offer the reader the most relevant and up-to-date information available and to build the foundation for answering the four research questions of this thesis.

3.1.2. Research questions

Comparing the manufacturing industry to other industries, one can state that the manufacturing sector scores relatively low in terms of digital intensity and in terms of transformation management intensity (Ebner et al., 2013). These facts lead to the following research questions:

To which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies?

How can digitalization help manufacturing companies in the field of manufacturing operations, supply chain and service maintenance?

What is the current level of digitalization among manufacturing companies?

What are the determinants of adoption of digital technologies in the manufacturing sector?

3.1.3. Research approach

The field of digitalization and the development towards Industry 4.0 is a fast-changing field, where new disruptive developments happen relatively often (Li et al., 2018; Oppitz and Tomsu, 2017). Therefore, the use of theoretical approaches and meta-analyses of data is relatively restricted, when it comes to the presented research questions. In order to generate a better understanding of the topic digitalization and the development towards Industry 4.0, and to get reliable and up-to-date answer to the research questions, the practical part of this thesis is based on structured expert interviews with representatives of companies, from the manufacturing sector.

3.1.4. Research design

The decision to conduct the research in form of structured expert interviews with representatives from companies from the manufacturing sector, was based on the reason to collect as much data as possible per sample. This has been done to get deeper insights of the interviewed companies, in order to develop a better understanding of the topics digitalization and Industry 4.0, from a practical point of view and to answer the four research questions. In order to get a differentiated view on the process of digitalization and how different companies approach the topic digitalization/Industry 4.0, the interviews have been conducted with four different companies from the manufacturing sector.

Concerning the selection of this sample, only manufacturing companies have been contacted via email in the first place. These companies had to fulfil the criteria of producing their goods in Austria and/or Southern Germany. Nevertheless, the manufacturing companies who were willing to participate in the interviews, for the practical part of this thesis, were selected as a sample. In order to increase the willingness of companies to participate in the research of this thesis, the interviews were completely anonymized, as soon as they were transcribed.

The interview questions were built on the basis of the previous literature review, as well as on the research questions of this thesis, as the results of the interviews should answer these four research questions. Therefore, the interview questions have been developed in English and were translated into German, before the interviews were conducted. German was used as language for the interviews, to ensure an equal understanding of the asked questions, regardless of the level of English of the single interviewee and to avoid any kind misunderstandings, caused by a potential language-barrier. Three interviews took place in face to face meetings and one interview was conducted via a telephone call. All interviews have been audio recorded in the first place and were later transcribed. After the interviews were conducted and transcribed into German, the transcribed interviews have been analyzed and the key results were translated into English. These results are presented in detail to the reader in chapter 4.1..

In order to answer the four research questions as reliable as possible, the interview was divided into four sections. Each section represented one research question. Within each section several questions were asked to the interviewee. Hence, the questions in each section were used to answer the overlaying research question. The four sections were named: Collaboration with external partners, impact on performance, current level of digitalization and determinants of adoption. In the first section, collaboration with external partners, six open-end questions were asked. In the second section, impact on performance, four open-end questions were asked to the interviewee. In the third section, current level of digitalization, seven open-end questions were asked. And in the fourth and final section, determinants of adoption, two questions with several suggestions for answers were asked to the interviewee. In this section the interviewees also had the possibility to choose several answers, as well as to give an open answer, which was not included in the previously suggested answers. The questions asked, in German and English, can be found in the Appendix of this thesis.

These interviews took place between the 22.06.2018 and the 27.06.2018. The interview with interviewee A from Company 1 took 17 minutes and was conducted via telephone. The interview with interviewee B from Company 2 took 16 minutes and took place during a face to face meeting. The interview with interviewee C from Company 3 took 32 minutes and was conducted in a face to face meeting. And the interview with interviewee D from Company 4 took 30 minutes and was again a face to face interview.

After the conducted interviews had been transcribed, the key results of these interviews were translated into English. Out of these results four tables were created, one for each research question. In these tables the into English translated answers of all four interviewed companies, for every question asked, are presented. Chapter 4.1. deals with these tabled in detail. Afterwards in chapter 4.2. the developed tables and the results of the interviews were analyzed and interpreted in detail, in order to present the reader, the most reliable answers for the four research questions. The conduced analysis and interpretation of the results in chapter 4.2. was supported by the software, Microsoft Excel. All this was done in the four subchapters of 4.2.. Moreover, in order to relate the theoretical part with the practical part of the thesis, the maturity model "Digitalization towards Industry 4.0" has been developed. This maturity model is presented in chapter 3.2. of this thesis and is based on the literature review and several pre-existing maturity models. The maturity model "Digitalization towards Industry 4.0" has been developed, to classify the digital maturity level of companies within the manufacturing sector. This has been done to gain deeper insights into the interviewed companies. Therefore, the developed maturity model has been applied to the answers of the four interviewed companies, in order to reveal their level of digital maturity. In doing that the maturity model “Digitalization towards Industry 4.0” strongly supported the process of finding reliable answers to the presented research questions.

3.2. Maturity model

In order to classify the digital maturity of companies within the manufacturing sector the maturity model “Digitalization towards Industry 4.0” has been developed in this thesis. The maturity model “Digitalization towards Industry 4.0” has been developed out of previously existing maturity models, as these maturity models are not meeting the requirements of the presented research questions and the underlying interview questions which were used in the company interviews. The previously existing maturity models, which were used to build this maturity model, are the models of Leyh et al. (2016), Geissbauer et al. (2016), Lichtblau et al. (2015) and Koch et al. (2014). The developed maturity model consists of five levels and six dimensions. These levels and dimensions will be described in detail in the following part. Moreover, at the end of chapter 3.2. the developed maturity model “Digitalization towards Industry 4.0” will be presented in detail to the reader.

Levels of the maturity model: Digitalization towards Industry 4.0: The maturity model aims to classify the current state of a company in terms of digitalization and how much the company already meets the requirements of Industry 4.0. Therefore, five levels of digital maturity were developed, these levels are: Maturity level 1: Process of digitalization has not started yet, maturity level 2: Digitalization of single departments, maturity level 3: Digitalization across departments, maturity level 4: Digitalization across the value chain and maturity level 5: Complete digitalization (Leyh et al., 2016; Lichtblau et al., 2015).

Dimension vertical integration of digital technologies: The dimension vertical integration of digital technologies measures to which extent digital technologies are implemented vertically across the value chain (Leyh et al., 2016). Vertical integration of digital technologies describes the integration of digital technologies within a company from the initial development of the product, over the manufacturing process, through the sale of the product, until the after sales service maintenance of the product (Koch et al., 2014; Lichtblau et al., 2015). All relevant data about significant processes like operating processes, manufacturing process, quality management and many more is in an digitalized company available in real time vertically throughout the whole value chain (Geissbauer et al., 2016; Leyh et al., 2016).

Dimension horizontal integration of digital technologies: The dimension horizontal integration of digital technologies measures to which extent digital technologies are implemented horizontally across the value chain. A key requirement for the dimension horizontal integration of digital technologies is, how advanced is the automatized and free flow of information across the horizontal levels within a company and across the borders of the company (Leyh et al., 2016). In addition, the flow of information ideally happens in real time (Geissbauer et al., 2016). Moreover, the horizontal integration of digital technologies has to be executed within a company as well as across several companies in order to meet the requirements for a completely digitalized company which reaches the conditions of Industry 4.0 (Koch et al., 2014; Lichtblau et al., 2015).

Dimension development of products: The dimension development of products measures to which extent the development process of products is supported by digital technologies. In order to meet the full requirements for a completely digitalized company, which reaches the level of Industry 4.0, the development of products needs to be completely digitalized. Therefore, it is extremely important that every step in the development process of a product is digitally depicted and the different development processes and steps are interconnected (Leyh et al., 2016; Lichtblau et al., 2015).

Dimension manufacturing operations: The dimension manufacturing operations measures to which extent digital technologies are implemented within the manufacturing process. In order to meet the all requirements for a completely digitalized company, the manufacturing process needs to be completely monitored and controlled by digital technologies. Moreover, machine to machine communication has to be fully implemented. As this builds the foundation for a self-controlled and flexible manufacturing process, which is better known as Industry 4.0 (Leyh et al., 2016; Lichtblau et al., 2015).

Dimension supply chain: The dimension supply chain measures to which extent digital technologies, which are driving the digitalization of the supply chain, are implemented into the supply chain of a company. In order to meet the full requirements for a completely digitalized company, which reaches the level of Industry 4.0, information has to be shared automagically and in real time throughout the whole supply chain (Geissbauer et al., 2016; Koch et al., 2014; Lichtblau et al., 2015).

Dimension service maintenance: The dimension service maintenance measures to which extent digital technologies are implemented in the field of service maintenance. In order to meet the full requirement for a completely digitalized company, which reaches the level of Industry 4.0, service maintenance has to be done automatically with the support of digital technologies. Therefore data driven and cloud based services are fully implemented (Leyh et al., 2016; Lichtblau et al., 2015).

Dimensions	***Maturity level 1: Process of digitalization has not started yet***	***Maturity level 2: Digitalization of single departments***	***Maturity level 3: Digitalization across departments***	***Maturity level 4: Digitalization across the value chain***	***Maturity level 5: Complete digitalization***
Vertical integration of digital technologies	No vertical integration of digital technologies has been implemented yet.	Vertical integration of digital technologies between single departments.	Vertical integration of digital technologies across departments.	Complete vertical integration of digital technologies throughout the whole company and partially across the value chain.	Complete vertical integration of digital technologies throughout the whole value chain.
Horizontal integration of digital technologies	No horizontal integration of digital technologies has been implemented yet.	Horizontal integration of digital technologies between single departments.	Horizontal integration of digital technologies across departments.	Complete horizontal integration of digital technologies throughout the whole company and partially across the value chain.	Complete horizontal integration of digital technologies throughout the whole value chain.
Development of products	The development of products is not supported by digital technologies.	The development of products is supported by single digital technologies.	The development of products is supported by multiple digital technologies.	The development of products is mostly digitalized and supported by a high variety of digital technologies.	The development of products is completely digitalized and the different processes and steps are interconnected.

Manufacturing operations	The manufacturing process is not monitored or controlled by digital technologies.	The manufacturing process is partially monitored and controlled by digital technologies. As partial digitalized sub processes are implemented.	The manufacturing process is mostly monitored and controlled by digital technologies. As internal processes have been digitalized.	The manufacturing process is almost completely monitored and controlled by digital technologies and M2M communication is partially implemented.	The manufacturing process is completely monitored and controlled by digital technologies and M2M communication is fully implemented.
Supply chain	Information is not shared via digital technologies across the supply chain.	Information is partially shared via digital technologies across the supply chain.	Information is partially shared automagically via digital technologies across the supply chain.	Information is shared automagically all over the supply chain.	Information is shared in real time automagically all over the supply chain.
Service maintenance	Service maintenance is done without the support of digital technologies.	Service maintenance is partially done with the support of digital technologies.	Service maintenance is done with the support of several digital technologies.	Service maintenance is mostly done with the support of digital technologies.	Service maintenance is done with the full support of digital technologies.

Table 1 – Maturity model: Digitalization towards Industry 4.0

(Geissbauer et al., 2016; Koch et al., 2014; Leyh et al., 2016; Lichtblau et al., 2015)

Chapter 4

4. Results and discussion

4.1. Results

In the following chapter the results of the interviews, with representatives of companies from the manufacturing sector, are present to the reader. After the interviews were conducted and transcribed into German, the transcribed interviews have been analyzed and the key results to every interview question were translated into English. The key results, of the conducted interviews, of all interviewed companies can be found in the subchapters of this chapter. These subchapters are divided and named like the four sections, which were asked to the interviewees in the interviews: Collaboration with external partners, impact on performance, current level of digitalization and determinants of adoption. The answers within these four sections will built the foundation for answering the overlaying research questions in chapter 4.2..

4.1.1. Results – Collaboration with external partners

Section 1 - Collaboration with external partners:				
Questions	**Company 1**	**Company 2**	**Company 3**	**Company 4**
In which sector is your company located?	- Electronic industry	- Conveyor technology - Factory equipment	- Wood-based materials - Energy - Laminates	- Electronic industry
How many employees are working for your company?	- 160	- 55	- 1200	- 450 to 550
What is your position within your company?	- Chief Executive Officer	- Constructor and Quality Manager	- IT and Organization Manager	- Plant Manager and Technology Manager of the senior management
Who is in charge of digitalization/Industry 4.0 within your company?	- Chief Executive Officer	- The general management	- IT department (as a driver and supervised by the parent company)	- IT department

Is the field of digitalization/Industry 4.0 handled completely internally by employees from your own company or do you have any form of external cooperation with partners like consulting companies or universities?	- SAP (external partner for digital software solutions and technology platforms)	- Yes, collaboration with external partners (due to their knowledge)	- SAP (external partner for digital software solutions)	- Mostly done internally - Manufacturing Execution System (MES) purchased (from external company)
If your company has any cooperation with external partners in the field of digitalization/Industry 4.0, how does this cooperation look like in practice?	- Usage of technology platforms of external partner (SAP)	- No experience	- Customer – supplier relationship	- Customer – supplier relationship

Table 2 – Section 1 – Collaboration with external partners

4.1.2. Results – Impact on performance

Section 2 - Impact on performance:				
Questions	**Company 1**	**Company 2**	**Company 3**	**Company 4**
Where is your company seeing the biggest chances when it comes to the implementation of digital technologies?	- Internet of Things (implemented into produced devices)	- Reduction of workforce - Increase of productivity	- Level of 0 defects - Optimization of processes - Contactless processes	- Self-operating CPS - Automatization of processes
How is digitalization/Industry 4.0 helping your company in the field of	- Digitalization of processes - Automatization of processes	- Not implemented	- Decreasing errors - Optimization of processes	- Reduction of costs

manufacturing operations?	- Flexibilization of processes			
How is digitalization/Industry 4.0 helping your company in the field of the supply chain?	- Stronger integration of suppliers - Paperless processes	- Not implemented	- Automagical tracking of goods - Contactless and paperless processes	- Reduction of manual processes - Closing of connectivity gaps
How is digitalization/Industry 4.0 helping your company in the field of service maintenance?	- Reduction of reaction time - Reduction of costs (Both through Remote availability of digital data)	- Not implemented	- Service maintenance is not offered	- Reduction of reaction time - Reduction of costs (Both through 24-hour direct service maintenance via web-services)

Table 3 – Section 2 – Impact on performance:

4.1.3. Results – Current level of digitalization

Section 3 - Current level of digitalization:				
Questions	**Company 1**	**Company 2**	**Company 3**	**Company 4**
How mature do you think your company is, in terms of digital maturity? On a scale from one to five, one means that the process of digitalization has not started yet and five means that the process of digitalization is completed.	2 - 3	2	3	4
How is your company approaching the topic vertical integration of digital technologies	- Not fully implemented between departments	- Not implemented	- Implemented between departments	- Widely implemented between departments and 75% the customers are integrated

within the company?				
How is your company approaching the topic horizontal integration of digital technologies?	- Implemented between single departments and partially suppliers are integrated	- Implemented between single departments	- Not implemented	- Implemented across departments, suppliers are to 20% and customers are to 50% integrated
To which extent is your company using digital technologies when it comes to the development of products?	- IoT - 3D-printing (for prototyping)	- Not used	- Single digital technologies are used (customer designs the product)	- Completely (But the development systems do not communicate automatically among each other)
To which extent is your company using digital technologies in the field of manufacturing operations?	- Control of the manufacturing process	- Not used	- Partial monitoring and controlling of the manufacturing process	- Almost completely - M2M communication - ERP system - EMS - Product IDs - CPS
To which extent is your company using digital technologies in the field of the supply chain?	- ERP system - Online platforms are partially used - Information is partially shared across the supply chain	- Not used	- Paperless transfer of information and partially autonomous transfer of information across the Supply Chain	- EDI - ERP system - MES - Connection of customers to the order system - Paperless transfer of information and partially autonomous transfer of information across the Supply Chain
To which extent is your company using digital technologies in the field of	- ERP system - Remote availability of digital data which can be transferred automatically	- Not used	- Service maintenance is not offered	- 24-hour direct service maintenance via a web-service - Remote availability of digital data

service maintenance?	

Table 4 – Section 3 – Current level of digitalization

4.1.4. Results – Determinants of adoption

Section 4 - Determinants of adoption:				
Questions	**Company 1**	**Company 2**	**Company 3**	**Company 4**
Why has your company adopted digital technologies to this extent?	- Productivity gains	- Productivity gains - Reduce costs - Stay up to date with the current technological development	- Productivity gains - Stay up to date with the current technological development	- Optimization of processes - Reduce costs - Market demand - Creating a competitive advantage
Why has your company not adopted other digital technologies?	- No demand from the market - Grown IT infrastructure (hard to change)	- No human resources - Too high costs	- No demand from the market - Technologies are not practical	- No demand from the market - Technologies are not practical - Low Return of Investment

Table 5 – Section 4 – Determinants of adoption

4.2. Analysis and interpretation of the results

The results of the interviews which were presented in the previous section, will be analyzed and interpreted in detail now. Therefore, this chapter offers the reader four subchapters, in which the answers of the four research questions will be discussed and finally presented to the reader. Each subchapter is dedicated to the analysis and interpretation of one section of the conducted interviews and to answer the overlying research question. Therefore, each subchapter is divided and named like the four sections, in which the results were presented. These subchapters are: Collaboration with external partners, impact on performance, current level of digitalization and determinants of adoption. Consequently, the results, of the previous chapter, are building the foundation for the analysis and interpretation of these results. Moreover, the in chapter 3.2. developed maturity model, “Digitalization towards Industry 4.0”, will be applied to classify the digital maturity of the interviewed manufacturing companies. In addition, the most significant finding of the conducted expert interviews will be highlighted and presented to the reader in detail.

4.2.1. Analysis and interpretation – Collaboration with external partners

The aim of this subchapter is it to find a reliable answer for the first research question. The first of the presented four research questions, is the question: "To which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies?". In order to answer this research question, the differences and similarities between the four interviewed companies, in terms of their level of collaboration with external partners, will be highlighted, analyzed and interpreted in detail.

Analyzing the interviewed companies, it became clear that the purchase of systems and software solutions of external partners is fairly common among the interviewed companies. As Company 1 and Company 3 purchased digital solutions from the German based software cooperation SAP.

"We are cooperating with external partners, like in our case SAP." (Company1)

Moreover, Company 4 handles most issues related to digitalization and Industry 4.0 internally. Nevertheless, they needed to purchase a Manufacturing Execution System (MES) from an external company.

"This MES system is implemented into our company with the help of an external partner." (Company 4)

In addition, the Company 3 had a rather contrary opinion compared to Company 2, on the experience external partners might have. Interviewee 3 was quite critical about the knowledge of external partners. Whereas Interviewee 2 emphasis the experience of external partners, in the field of digitalization and Industry 4.0, as the main reason to collaborate with them.

"So, what do you want to buy from external partners? And how much experience do they really have?" (Company 3)

"We work together with external partners, because they have experience with digitalization/Industry 4.0. (...) I think Company 2 will mainly work with external partners, as we are expecting the biggest input from them." (Company 2)

Another point to consider is the question, how does the cooperation of manufacturing companies with external work in practice. Concerning this question, the results are again relatively diverse. For instance, Company 1 uses technology platforms as well as digital custom-made solutions of external partners.

“We are partially using already existing technology platforms. And we are developing together with our external partners solutions, which are customized for our needs.” (Company 1)

In contrast to Company 1, Company 4 bought a system from an external partner and implemented it with the expertise of their own employees. Therefore, they described their cooperation with the external partner straightforward.

“A customer-supplier relationship. (...) But the integration into our company is then executed by our own employees.” (Company 4)

Analyzing the four interviews, it becomes clear that the interviewees had different opinions on the experience and knowledge of external partners in the fields of digitalization and Industry 4.0. Moreover, the companies had diverse approaches towards the collaboration with external partners. As some companies work more closely together with external partners than other companies do. It also appeared that mainly digital software solutions are purchased from external partners.

All in all, the presented results answer the first research question, “To which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies?”. The extent to which the interviewed manufacturing companies collaborate with external partners, in the field of digitalization, does highly vary between the four interviewed companies. This might be caused by the different experiences these companies had with external partners, the goals these companies want to achieve and the challenges these companies are currently facing.

4.2.2. Analysis and interpretation – Impact on performance

The aim of this subchapter is it to find a reliable answer to the second research question, “How can digitalization help manufacturing companies in the field of manufacturing operations, supply chain and service maintenance?”. In order to answer this, the differences and similarities of the four interviewed companies will be highlighted, analyzed and interpreted in detail within this subchapter.

When analyzing the four conducted interviews, it becomes clear that the four interviewed companies see the biggest chances of digitalization and Industry 4.0, for their companies, in different technologies and certain developments these technologies are expected to cause. For instance, Company 1 sees their biggest chances in the field of the Internet of Things, whereas Company 4 finds their biggest opportunities of digitalization and Industry 4.0, for their company, in cyber physic systems. In addition, Company 2 sees their greatest chances, related to digitalization and Industry 4.0, in an increase of quality and in a decrease of workforce within the production process.

"For us the biggest chances are in the field of IoT. As we as a company transform the products that we deliver today into IoT devices." (Company 1)

"Cyber Physic systems, who are self-operating. (...) That simply means automatization through digital technologies" (Company 4)

"Primarily in the production process of our company, we are seeing the biggest chances. (...) Mainly because we can reduce the number of employees and can execute the nightshift even without employees. (...) And we can achieve a higher level of precision [through the implementation of digital technologies]." (Company 2)

Moreover, when it comes to the support of digitalization and Industry 4.0 in the fields of manufacturing operations, supply chain and service maintenance, the optimization of processes is a promising issue to the interviewed manufacturing company. For instance, Company 1 described the effects of digitalization and Industry 4.0 on the manufacturing process.

"[With the help of digitalization/Industry 4.0] processes can be digitalized and so these processes become paperless. Through that these processes become automatized and can also become increasingly flexible." (Company 1)

Additionally, Company 3 describes how digitalization and Industry 4.0 positively influences processes within the supply chain.

"The whole intra-logistic in our company is highly automatized. (...) If movements happen, these movements are tracked digital automatically in the system" (Company 3).

Furthermore, Company 4 highlighted how digitalization and Industry 4.0 increased their performance and reduced costs in the field of service maintenance.

"[We offer] remote maintenance within our 24-hour maintenance service. This saves our company a lot of business trips and on-site service technicians. (...) [This also leads] to lower costs because the service technician is not on-site. This means that the service technician can directly access the machine via a web-service and execute the required adjustments." (Company 4)

All in all, the presented results answer the second research question, “How can digitalization help manufacturing companies in the field of manufacturing operations, supply chain and service maintenance?”. Digitalization can support manufacturing companies in their manufacturing operations, in the supply chain and when it comes to service maintenance, through the digitalization and the subsequent automation of processes. Therefore, digitalization can decrease defects, can reduce costs and consequently digitalization can also increase productivity.

4.2.3. Analysis and interpretation – Current level of digitalization

The goal of this subchapter is it to find a reliable answer for the third research question: “What is the current level of digitalization among manufacturing companies?” and to understand at which level, in the process of digitalization, companies within the manufacturing sector currently are. Therefore, the in chapter 3.2. developed maturity model, “Digitalization towards Industry 4.0”, will be applied to the answers of the interviewed company representatives. This is done to classify the level of digital maturity of the interviewed companies. Additionally, the differences and similarities between the four interviewed companies will be highlighted, analyzed and interpreted in detail.

All four interviewed companies have been analyzed and classified in terms of their digital maturity using the maturity model, “Digitalization towards Industry 4.0”. These results of the classification of the interviewed companies can be regarded in detail in the following figure (Figure 1).

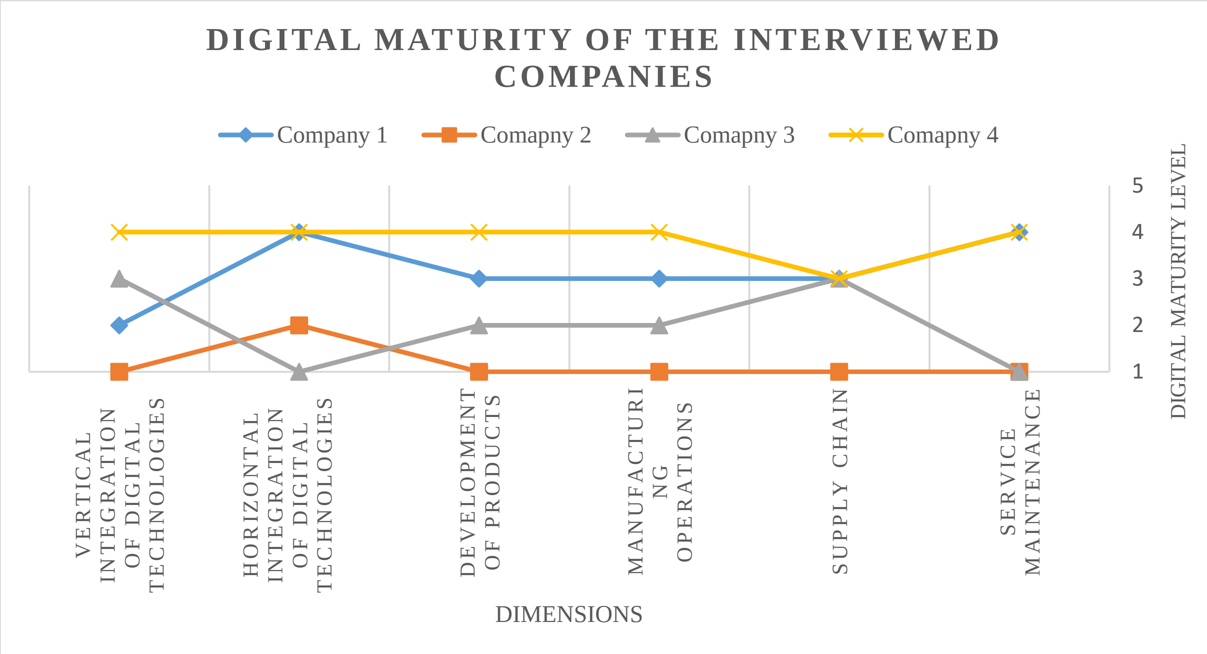

Figure 1 – Digital maturity of the interviewed companies
(classified with the maturity model “Digitalization towards Industry 4.0”)

Company 1, estimated that their current digital maturity level is between 2 and 3, so around 2.5. After analyzing the results of the figure (Figure 1), it becomes clear that the overall average maturity level of Company 1, according to the maturity model “Digitalization towards Industry 4.0”, is 3.2. Therefore, Company 1 underestimated their digital maturity level by 0.7 levels. In addition, the minimum maturity level of Company 1 was reached with level 2 in the dimension “Vertical Integration of Digital Technologies”. Whereas their highest level was reached in the dimensions “Horizontal Integration of Digital Technologies” and “Service Maintenance” with level 4.

Company 2, estimated that their current digital maturity level is 2. Analyzing the results, which are offered in the figure (Figure 1), it becomes clear that the overall average maturity level of Company 2, according to the maturity model “Digitalization towards Industry 4.0”, is 1.2. Hence, Company 2 reached the lowest score of all interviewed companies and overestimated their digital maturity by 0.8 levels. Moreover, Company 2 reached level 1 in five out of six dimensions. The only dimension where Company 2 reached the second level of digital maturity and therefore their maximum, is the dimension “Horizontal Integration of Digital Technologies”.

In addition, Interviewee 2 anticipated that result, by mentioning that Company 2 is just getting started when it comes to the process of digitalization.

“We had some talks and several meetings [about digitalization], but until now concerning [the process of digitalization] just a few things were actually put into practice.” (Company 2)

Company 3, estimated that their digital maturity level is currently 3. The results presented in the figure (Figure 1) showed that Company 3 overestimated their digital maturity. As the overall average maturity level, according the maturity model “Digitalization towards Industry 4.0”, is 2.0. In addition, the representative of Company 3 pointed out that the topic horizontal integration of digital technologies is not interesting for Company 3, due to their product portfolio. Moreover, Company 3 does not offer service maintenance. Therefore Company 3 reached level 1 in the maturity level in the dimensions “Horizontal Integration of Digital Technologies” and “service maintenance”. Interviewee 3 explained the absence of Company 3 from the dimensions “Horizontal Integration of Digital Technologies” with the nature of their products.

“[Horizontal integration] is not a topic [for our company]. Therefore, someone needs the right products, where this kind of digitalization can be used. Our wood-based materials definitely do not match with [the Horizontal integration of digital technologies] and in our opinion, that does not offer any advantages [to us].” (Company 3)

However, through the exclusion of the two dimensions “Horizontal Integration of Digital Technologies” and “service maintenance” the average maturity level of Company 3 increases to 2.5. Additionally, Company 3 highest level of digital maturity is level 3, which was reached in the dimensions “Vertical Integration of Digital Technologies” and “supply chain”.

Company 4, estimated that their digital maturity level is currently at 4. The results, which were presented in the figure (Figure 1), showed that Company 4 slightly underestimated their overall maturity level. As according to the maturity model “Digitalization towards Industry 4.0”, the overall average maturity level of Company 4 is 3.8. Therefore, Company 4 reached the highest score of all four interviewed companies. Furthermore, Company 4 reached their maximum level with the maturity level 4 in five out of six dimensions. As Company 4 lowest maturity level is level 3, which was reached in the dimension “supply chain”.

Analyzing the presented figure (Figure 1), one can state that the outcomes of the four interviewed companies are relatively diverse, as in terms of the six dimensions, the results of the interviewed companies showed different levels of digital maturity. The overall average maturity level of all interviewed companies, over all six dimensions, according to the maturity model “Digitalization towards Industry 4.0”, is 2.7. Furthermore, the standard deviation between the estimations, made by the interviewed companies, and the overall average maturity level, measured by the maturity model "Digitalization towards Industry 4.0", is 0.6 levels. In addition, three out of four interviewed companies overestimated their level of digital maturity. Only Company 1 underestimated their digital maturity level.

Moreover, the two interviewed companies with the highest measured maturity level are Company 1, with an average maturity level of 3.2 and Company 4, with an average maturity level 3.8. Both of them are located in the same sector, the electronic industry. Therefore, the industrial sector in which a company is located in and the products which the company produces, might influence the use of digital technologies and consequently also the overall digital maturity level of a manufacturing company.

All in all, the presented results answer the third research question, "What is the current level of digitalization among manufacturing companies?". As the due to the developed maturity model, "Digitalization towards Industry 4.0", the average current level of digitalization among the interviewed manufacturing companies is 2.7. This means that the average interviewed company is currently located between maturity level 2 (digitalization of single departments) and maturity level 3 (digitalization across departments), when it comes to their digital maturity.

4.2.4. Analysis and interpretation – Determinants of adoption

The aim of this subchapter is it to find a reliable answer for the fourth and final research question: "What are the determinants of adoption of digital technologies in the manufacturing sector?". In order to answer this research question, the differences and similarities of the four interviewed companies will be highlighted, analyzed and interpreted in detail.

When analyzing the four conducted interviews, it became clear that three answers often occurred when the question, "why has your company adopted digital technologies to this extent?", was asked. One reason which was frequently mentioned were productivity gains. Another reason which occurred relatively often was the reduction of costs. And the third answer, which frequently appeared, was the desire to stay up to date with the latest technological development. Company 2 and Company 3 highlighted, that two out of these three determines are the main reasons for the use of digital technologies within their companies.

"To reduce costs and to increase productivity are definitely the main reasons (…) why Company 2 implemented digital technologies to this extent." (Company 2)

"To stay up to date with the technological and the realize productivity gains." (Company 3)

Concerning the questions, why manufacturing companies have not adopted other digital technologies? The missing demand from the market to implement other digital technologies, was the most frequently appearing answer.

“I would say that contemporarily, this pressure from the market to implement special technologies is not there yet.” (Company 1)

“A Return of Investment is not given for us, because the opportunities of use, [for other digital technologies], are limited. That means to us, that the investment [into other digital technologies] is way too high and that there is no demand from the market.“ (Company 4)

All in all, the presented results answer the fourth research question, “What are the determinants of adoption of digital technologies in the manufacturing sector?”. The interviews showed that the most frequently named determines of adoption for digital technologies were: Productivity gains, the reduction of costs, the market demand and the drive to stay up to date with the latest technological developments.

4.3. Limitations and further research

This thesis offers promising content as an overview about the given topic, Industry 4.0 and digitalization, as well as self-conducted interviews with manufacturing companies. Due to the limited amount of up-to date research in this field, this thesis can be definitely seen as an extension to the literature, which is currently available. Especially, the conducted interviews with representatives from manufacturing companies can be a valuable source for future research.

However, this thesis is also facing several limitations. Regarding the literature review, in some cases older sources of data have been used, as newer sets of data were not available. This data may not be totally up-to data anymore and therefore the quality of future applications might be limited. Concerning the practical part of this thesis, only four interviews have been conducted. Therefore, the presented results cannot be generalized due to the small number of samples. Hence, it is easily possible that different results can be generated if the same method is used with other companies in the same region, as the sample is relatively small. Another point to consider is that this thesis is mainly focusing on the manufacturing sector. Consequently, there might be totally different outcomes when applying the same research to other sectors and industries.

Moreover, the interview partners have different professions and they also have an unequal background of knowledge, as some of them work in different positions and fields. Therefore, they might have a completely different view on the topics, digitalization and Industry 4.0. This means, that the given answers come from diverse perspectives and that these perspectives are based on different knowledge and experience. Dissimilar interview partners might also have a different perception and a different understanding of terminologies like digitalization, Industry 4.0. and digital technologies. Consequently, the answers of the four interview partners might not describe the same issues from the same perspective. Hence, this could influence the outcomes of the research in a significant way. Additionally, manufacturing companies who are not interested into the topics digitalization and Industry 4.0, might not even want to participate within a survey, which deals with the topics Industry 4.0 and digitalization and is based on interviews with company representatives. Therefore, it is possible that only manufacturing companies, who actively discuss and approach the topics digitalization and Industry 4.0, are interested in participating in a research, which is based on interviews with company representatives.

Based on the limitations of this thesis future research could include, qualitative studies with a statistically significant number of participating companies. So, the results of future researches can be generalized. Furthermore, ideally future interview partners or participants of research should have the same background of knowledge. For instance, working in approximately the same job position or department. These steps should be done, to ensure that the questions are answered with more or less the same background of knowledge and an equal understanding of the topic.

Furthermore, the two companies with the highest measured maturity level, within the conducted research, were both located in the same industry, the electronic industry. Therefore, future research could also focus on specific industries within the manufacturing sector. Moreover, also the comparison of companies from the manufacturing sector to companies from other sectors might be a promising field for future research.

Chapter 5

5. Conclusion and recommendations

To conclude, this master thesis offers the reader deep insights into the topics of digitalization and the development towards Industry 4.0: particularly the manufacturing sector has been in the focus of this thesis. Therefore, the practical part of this thesis dealt mainly with the topics, Industry 4.0, digitalization, digital intensity within the manufacturing sector and with the four clusters of disruptive technologies. Within these four clusters the most relevant digital technologies were presented in detail to the reader. In addition, for every analyzed digital technology, a general overview was given, followed by an example of implementation, then both the benefits and the costs were discussed and finally the risk related to each digital technology was analyzed in a critical way. Moreover, the literature highlighted the enormous, economic and social impacts previous industrial revolutions had on the economy and society itself and that Industry 4.0 is not yet an industrial revolution in the dimension of the previous three industrial revolutions. Additionally, current trends and future projections concerning economic as well as social impacts of digitalization were presented.

In order to answer the four presented research questions in an extensive way the practical part of this thesis was built on self-conducted interviews with representatives from manufacturing companies. The questions which the interviewees were confronted with during these interviews were based on the theoretical part of this thesis and their purpose was to answer the four research questions, whose results were subsequently analyzed. This analysis was conducted with the support of the self-developed maturity model "Digitalization towards Industry 4.0". This maturity model was designed to identify at which level of digital maturity the interviewed manufacturing companies currently are and consequently answer one of the four research questions. The other three research questions were as well answered with the four conducted company interviews.

Concerning the first research question, "To which extent do manufacturing companies collaborate with external partners when it comes to the implementation of digital technologies?", it appeared that the extent to which the interviewed companies collaborate with external partners in the field of digital technologies highly varies between the companies, as some companies work closer together with external partner than others. It seemed that mainly digital software solutions were purchased from external partners. Regarding the second research question, “How can digitalization help manufacturing companies in the field of manufacturing operations, supply chain and service maintenance?”, it was possible to conclude that digitalization can support manufacturing companies in their manufacturing operations, in the supply chain and when it comes to service maintenance, through digitalization and the subsequent automation of processes. Thus, digitalization can decrease defects, reduce costs and consequently increase productivity. For the third research question, “What is the current level of digitalization among manufacturing companies?”, the developed maturity model “Digitalization towards Industry 4.0” was applied. By doing so, the results of the conducted company interviews revealed, that according to the maturity model “Digitalization towards Industry 4.0” the average current level of digitalization among the interviewed manufacturing companies was level 2.7. This means that the average interviewed company was currently located between maturity level 2 (digitalization of single departments) and maturity level 3 (digitalization across departments), when it comes to their digital maturity. Concerning the fourth and final research question, “What are the determinants of adoption of digital technologies in the manufacturing sector?”, it was revealed that the most frequently mentioned determinants of adoption for digital technologies, among the interviewed companies, were productivity gains, the reduction of costs, the market demand and the drive to stay up to date with the latest technological developments.

By analyzing the interviews, it can be stated that the interviewed manufacturing companies were definitely at the beginning or in the middle of their digital transformation towards Industry 4.0. They were all aware of the significant impacts digital technologies and digitalization could have on them. Therefore, all the interviewed companies were planning to increase their digital maturity level, as all of them were expecting to approach the topics digitalization and Industry 4.0 increasingly intense in the future. During the company interviews as well as during the analysis and interpretation it was highlighted that in some departments and even in whole companies, the process of digitalization was just getting started and that many indicatives concerning Industry 4.0 were currently planned or just started. Moreover, none of the four interviewed companies reached maturity level 5, of the developed maturity model, in a single of the six dimensions. Hence, manufacturing companies still had room for implementing digital technologies, which drive the change towards Industry 4.0. Therefore, it can be stated that the process of digitalization in the manufacturing sector is far away from being completed.

Nevertheless, all interviewed companies regarded the topics digitalization and Industry 4.0 extremely seriously and considered it to be a crucial aspect in the long term rather than a simple trend.

Moreover, a certain gap between literature and practice was spotted, as the literature especially highlights specific technologies which are not or rarely implemented into manufacturing companies yet. Therefore, it was hard to find concrete examples of certain technologies within that field.

All in all, this master thesis shows which promising opportunities manufacturing companies have and which challenges they are facing through the process of digitalization and the development towards Industry 4.0. This thesis demonstrates that the manufacturing sector is about to be digitalized, through the implementation of digital technologies. Technologies, which have the potential of transforming companies, business models and the whole industrial sector. Hence, new competitors could rapidly change the market through the use of digital technologies like it already happened in other industrial sectors. Manufacturing companies need to be flexible and have to drive the change towards their digitalization, before they get beaten by new emerging or faster changing competitors and consequently become obsolete.

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7. Appendix

Appendix 1: Interview Questions English

Section 1 - Collaboration with external partners:

1. In which sector is your company located?
2. How many employees are working for your company?
3. What is your position within your company?
4. Who is in charge of digitalization/Industry 4.0 within your company?
5. Is the field of digitalization/Industry 4.0 handled completely internally by employees from your own company or do you have any form of external cooperation with partners like consulting companies or universities?
6. If your company has any cooperation with external partners in the field of digitalization/Industry 4.0, how does this cooperation look like in practice?

Section 2 - Impact on performance:

1. Where is your company seeing the biggest chances when it comes to the implementation of digital technologies?
2. How is digitalization/Industry 4.0 helping your company in the field of manufacturing operations?
3. How is digitalization/Industry 4.0 helping your company in the field of the supply chain?
4. How is digitalization/Industry 4.0 helping your company in the field of service maintenance?

Section 3 - Current level of digitalization:

1. How mature do you think your company is, in terms of digital maturity? On a scale from one to five, one means that the process of digitalization has not started yet and five means that the process of digitalization is completed.
2. How is your company approaching the topic vertical integration of digital technologies within the company?
3. How is your company approaching the topic horizontal integration of digital technologies?
4. To which extent is your company using digital technologies when it comes to the development of products?

5. To which extent is your company using digital technologies in the field of manufacturing operations?
6. To which extent is your company using digital technologies in the field of the supply chain?
7. To which extent is your company using digital technologies in the field of service maintenance?

Section 4 - Determinants of adoption:

1. Why has your company adopted digital technologies to this extent?

- To reduce costs
- To realize productivity gains
- To stay up to date with current level of technological development (of competitors)
- Because the existing infrastructure supports digital technologies
- Because supplier and/or costumers require these technologies
- Other reasons

2. Why has your company not adopted other digital technologies?

- No or limited productivity gains
- Too high costs
- The return of investment is too low
- The existing infrastructure within the company is not supporting these digital technologies
- Supplier and/or consumer are not using these digital technologies, therefore the digital connectivity gap would remain
- No or low competitive pressure to adopt these digital technologies
- Technologies are not practical for our company
- The advantages of these technologies are debatable
- Not aware about other digital technologies
- Other reasons

Appendix 2: Interview Questions German

Themenkomplex 1 – Zusammenarbeit mit externen Partnern:

1. In welchem Sektor ist Ihr Unternehmen tätig?
2. Wie viele Mitarbeiter arbeiten für Ihr Unternehmen?
3. Welche Position haben Sie in Ihrem Unternehmen?
4. Wer ist in Ihrem Unternehmen für das Thema die Digitalisierung / Industrie 4.0 verantwortlich?
5. Wird der Bereich Digitalisierung / Industrie 4.0 vollständig intern von eigenen Angestellten betreut oder besteht eine Kooperation mit externen Partnern wie Unternehmensberatungen oder Universitäten?
6. Wenn Ihr Unternehmen mit externen Partnern im Bereich Digitalisierung / Industrie 4.0 kooperiert, wie sieht diese Kooperation in der Praxis aus?

Themenkomplex 2 – Einfluss auf Performance:

1. Wo sieht Ihr Unternehmen die größten Chancen für die Implementierung digitaler Technologien?
2. Wie unterstützt Digitalisierung / Industrie 4.0 Ihr Unternehmen in der Produktion?
3. Wie unterstützt Digitalisierung / Industrie 4.0 Ihr Unternehmen im Bereich der Supply Chain?
4. Wie unterstützt Digitalisierung / Industrie 4.0 Ihr Unternehmen im Service / in der Wartung?

Themenkomplex 3 – Derzeitiges Level:

1. Wie würden Sie Ihr Unternehmen auf einer Skala von eins bis fünf in Bezug auf digitale Reife einschätzen? Eins bedeutet, dass der Prozess der Digitalisierung noch nicht begonnen hat und fünf bedeutet, dass der Prozess der Digitalisierung abgeschlossen ist.
2. Wie geht Ihr Unternehmen mit dem Thema vertikale Integration von digitalen Technologien im Unternehmen um?
3. Wie geht Ihr Unternehmen mit dem Thema horizontale Integration von digitalen Technologien um?
4. In welchem Umfang nutzt Ihr Unternehmen digitale Technologien, wenn es um die Entwicklung von Produkten geht?

5. In welchem Umfang nutzt Ihr Unternehmen digitale Technologien im Bereich der Produktion?
6. In welchem Umfang nutzt Ihr Unternehmen digitale Technologien im Bereich der Supply Chain?
7. In welchem Umfang nutzt Ihr Unternehmen digitale Technologien im Bereich Service / Wartung?

Themenkomplex 4 – Determinanten der Adaption

1. Warum hat Ihr Unternehmen digitale Technologien in diesem Umfang eingeführt?

- Um Kosten zu reduzieren
- Um Produktivitätsgewinne zu realisieren
- Um auf dem neuesten Stand der technologischen Entwicklung (der Wettbewerber) zu sein
- Da die vorhandene Infrastruktur digitale Technologien unterstützt
- Da Lieferanten und / oder Kunden dies Technologien erwarten
- Andere Gründe

2. Warum hat Ihr Unternehmen keine anderen digitalen Technologien übernommen?

- Keine oder begrenzte Produktivitätsgewinne
- Zu hohe Kosten
- Der Return of Investment ist zu niedrig
- Die bestehende Infrastruktur im Unternehmen unterstützt diese digitalen Technologien nicht
- Lieferanten und / oder Kunden nutzen diese digitalen Technologien nicht, daher würde eine digitale Verbindungslücke bestehen bleiben
- Kein oder geringer Wettbewerbsdruck um diese digitalen Technologien zu übernehmen
- Diese Technologien sind für unser Unternehmen nicht praktikabel
- Die Vorteile dieser Technologien sind umstritten
- Keine Kenntnis von anderen digitalen Technologien
- Andere Gründe

Appendix 3: Classification of the interviewed companies with the maturity model “Digitalization towards Industry 4.0”

Dimensions	*Maturity level 1: Process of digitalization has not started yet*	*Maturity level 2: Digitalization of single departments*	*Maturity level 3: Digitalization across departments*	*Maturity level 4: Digitalization across the value chain*	*Maturity level 5: Complete digitalization*
Vertical integration of digital technologies	Company 2	Company 1	Company 3	Company 4	
Horizontal integration of digital technologies	Company 3	Company 2		Company 1 Company 4	
Development of products	Company 2	Company 3	Company 1	Company 4	
Manufacturing operations	Company 2	Company 3	Company 1	Company 4	
Supply chain	Company 2 (No service maintenance offered by Company3)		Company 1 Company 3 Company 4		
Service maintenance	Company 2 (no service maintenance offered by Company 3)			Company 1 Company 4	