Master Thesis

# Analysis of the Theoretical Framework and Practical Applications of current Industry 4.0 Measures to support a Use Case Implementation

*Markus Egger*

Institute of Production Science and Management

Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

Graz, 2016

**Statutory Declaration**

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, ________________ ___________________

(signature)

# Abstract

The initiative known under the designation *Industry 4.0* established the introduction of new technologies into the industrial environment and enable European enterprises to stay competitive. With the Internet of Things, which refers to the progressive integration of everyday objects to the Internet, the foundation for the now imminent fourth industrial revolution was laid. In Industry 4.0 different components are equipped with information and communication technologies to become so-called cyber-physical systems. The thus resulting extra level of functionality enables these systems to meet the general requirements of the overall system are always considered enabling decentralized and autonomous decision making. This should, amongst others increase the efficiency in production achieved and the increasing desire for individually configurable products should be met.

In this work it was investigated how these theoretical approaches have so far been implemented in practice. In the beginning the underlying concepts have been identified. These concepts highlight the need for a holistic implementation in order to sustainably leverage the so far hidden potentials. The focus then was put on those technologies, which could be identified as the basic building blocks for the realization of this initiative. Current practical implementations in the various industry sectors and future fields of application technologies have been analyzed including the experiences of experts from the industry to determine their scope of applicability.

To evaluate the findings so far an implementation of a practical use case in a company has been identified, which could be improved by implementing industry 4.0 measures. By connecting mobile devices to the already existing IT infrastructure using a superordinate platform, a decentralized, context-based and user specific provision of information was realized. Through the installation of this measure a reduction of the response time between the occurrence of a machine failure and the moment the maintenance worker is informed has been reduced significantly. It has thus been shown that the first steps towards industrial 4.0 can be realized that even at relatively low cost and little effort.

By a comparison of the theoretical and the practical approach a significant discrepancy between the two could be identified. On one hand, the practical implementation of certain technologies is already close to industrialization, on the other hand a holistic implementation still holds several challenges in research and development.

# Kurzfassung

Die unter der Bezeichnung *Industrie 4.0* bekannt gewordenen Initiative soll durch die Einführung neuer Technologien in das industrielle Umfeld die Wettbewerbsfähigkeit europäischer Unternehmen sichern. Mit dem Internet der Dinge, welches die fortschreitende Anbindung von Alltagsgegenständen an das Internet bezeichnet, wurde der Grundstein für die nun bevorstehende vierte industrielle Revolution gelegt. Bei Industrie 4.0 sollen die verschiedensten Objekte unter Einbeziehung von Informations- und Kommunikationstechnologien zu so genannte Cyber-Physical-Systems werden. Die dadurch entstehende zusätzliche Ebene von Funktionen befähigt diese Systeme dezentral und autonom Entscheidungen zu treffen, wobei die übergeordneten Anforderungen des Gesamtsystems stets berücksichtigt werden. Dadurch sollen unter anderem Effizienzsteigerungen in der Produktion erzielt und dem Wunsch nach individuell konfigurierbaren Produkten nachgekommen werden.

Im Rahmen dieser Arbeit wurde untersucht, inwiefern diese theoretischen Ansätze bereits in der Praxis umgesetzt worden sind. Dabei wurden zuerst die zugrundeliegenden Konzepte ermittelt. Diese Konzepte verdeutlichen die Notwendigkeit einer ganzheitlichen Umsetzung, um nachhaltig die bisher ungeahnten Potentiale voll ausschöpfen zu können. Weiter wurde der Fokus auf die Technologien gelegt, welche als die elementaren Bausteine zur Realisierung des Vorhabens identifiziert werden konnten. Aktuelle praktische Umsetzungen aus den diversen Branchen sowie zukünftige Einsatzgebiete noch nicht ausgereifter Technologien konnten unter Einbeziehung von Experten aus der Industrie auf deren breite Anwendbarkeit analysiert werden.

Die aus der Literaturrecherche und den Experteninterviews gewonnenen Erkenntnisse halfen bei der Umsetzung eines Industrie 4.0 Anwendungsfalls in einem Unternehmen. Hierbei wurde ein Prozess ausgewählt, welcher nach umfassender Analyse ein erhebliches Optimierungspotential aufwies. Dieser Prozess konnte mithilfe der Anbindung von mobilen Endgeräten an die schon bestehende IT Infrastruktur digitalisiert werden, wodurch zusätzlich auch noch eine Teilautomatisierung der Abläufe realisiert werden konnte. Dadurch wurde erreicht, dass die Reaktionszeit zwischen Auftreten eines Maschinenfehlers und dem Eintreffen des Instandhaltungspersonal deutlich verringert werden konnte. Es wurde somit gezeigt, dass auch mit relativ geringen Mitteln und wenig Aufwand die ersten Schritte in Richtung Industrie 4.0 realisiert werden können.

Durch die Gegenüberstellung von theoretischer Forschung und praktischer Umsetzung konnte zum Teil eine erhebliche Diskrepanz zwischen den beiden festgestellt werden. Einerseits ist die praktische Umsetzung gewisser Technologien schon nahe der Industrialisierung, andererseits sind für eine ganzheitliche Umsetzung noch einige Herausforderungen in Forschung und Entwicklung zu bewältigen.

# Table of content

1 Introduction ... 1

1.1 Objectives ... 2

1.2 Methodical approach ... 2

2 Literature Review on Industry 4.0 ... 4

2.1 Industry 4.0 as Successor of the Internet of Things ... 5

2.2 Internet of Things vs. Industrial Internet vs. Industry 4.0 ... 5

2.3 Reasons for Industry 4.0 ... 7

2.3.1 Histroic justification ... 7

2.3.2 Future necessity ... 7

2.4 The Potential Impact of the Internet of Things ... 10

2.5 Industry 4.0's Potential Impact ... 11

2.6 The Basic Concepts ... 11

2.6.1 Cyber Physical Systems ... 12

2.6.2 Vertical and Horizontal Integration ... 14

2.6.3 Consistent Engineering ... 16

2.6.4 Decentralization ... 17

2.6.5 Interdependencies of the Concepts ... 18

2.6.6 Requirements for Implementation - Standardization ... 18

2.7 Technologies Empowering I4.0 ... 20

2.7.1 Big Data and Analytics ... 20

2.7.2 The Cloud ... 26

2.7.3 Advanced robots ... 30

2.7.4 Industrial Internet of Things ... 34

2.7.5 Additive manufacturing ... 39

2.7.6 Augmented reality ... 45

2.7.7 Smart Mobile Devices ... 50

2.7.8 Summary of the Presented Technologies ... 53

2.8 Implemenation Challenges of I4.0 in General ... 54

2.8.1 Costs ... 54

2.8.2 Cybersecurity ... 55

2.8.3 Complexity ..... 55
2.8.4 Lack of Talent ..... 56
2.8.5 Standardization ..... 57
2.9 Recent Developments and Near Future ..... 57
2.10 Findings ..... 61
3 Evaluation of the Literature Review ..... 65
3.1 Company Selection ..... 65
3.2 Approach ..... 66
3.3 Test Fuchs ..... 66
3.3.1 Implemented Technologies and Use Cases ..... 67
3.3.2 Challenges During Implementaion ..... 68
3.3.3 Conclusion of the Interview ..... 68
3.4 Ginzinger Electronic Systems ..... 68
3.4.1 Implemented Technologies and Use Cases ..... 68
3.4.2 Challenges During Implementaion ..... 70
3.4.3 Conclusion of the Interview ..... 70
3.5 Fill ..... 70
3.5.1 Implemented Technologies and Use Cases ..... 70
3.5.2 Challenges During Implementaion ..... 72
3.5.3 Conclusion of the Interview ..... 72
3.6 Kresta Industries ..... 73
3.6.1 Implemented Technologies and Use Cases ..... 73
3.6.2 Challenges During Implementation ..... 74
3.6.3 Conclusion of the Interview ..... 74
3.7 Resumee of the Evaluation ..... 74
4 Use Case ..... 77
4.1 Company Presentation - EVG ..... 77
4.2 Methodological Approach ..... 78
4.3 Project Definition ..... 80
4.3.1 Use case 1 – Optimizing the Maintenance and Repair Procedure ..... 81
4.3.2 Use Case 2 – Tool Management ..... 82
4.3.3 Decision on Use Case ..... 82

4.4 Understand Process ... 82
4.4.1 Previous Process ... 83
4.4.2 Overview Status Quo ... 83
4.5 Improve Process ... 89
4.6 Measure and Monitor / Continuously Improve Process ... 96
4.7 Learnings of the Use Case ... 97
5 Summary ... 98
6 Outlook ... 100

# List of figures


FIGURE 1-1 METHODICAL APPROACH ........ 3
FIGURE 2-1 THE FOUR STEPS OF INDUSTRIAL REVOLUTION ........ 4
FIGURE 2-2 SCOPE AND REACH OF DIFFERENT INTERNETS ........ 6
FIGURE 2-3: MEGATRENDS OF FUTURE PRODUCTION ........ 8
FIGURE 2-4: THE SCOPE OF IOT ........ 11
FIGURE 2-5 ELEMENTS OF A CPS ........ 13
FIGURE 2-6: 5C CPS STRUCTURE OF A TOOL MACHINE ........ 14
FIGURE 2-7: VERTICAL INTEGRATION - AUTOMATIZATION PYRAMID ........ 15
FIGURE 2-8: THREE ELEMENTS OF THE HORIZONTAL INTEGRATION ........ 16
FIGURE 2-9: DIGITAL TO PHYSICAL WORLD ........ 17
FIGURE 2-10: STANDARDIZATION PROCESS ........ 19
FIGURE 2-11 RELEVANT TECHNOLOGIES ........ 20
FIGURE 2-12: GREATEST CONCERNS ABOUT THE USE OF BIG DATA ANALYTICS ........ 23
FIGURE 2-13: BUSINESS MODEL CHANGES MADE BY COMPANIES DUE TO IOT TECHNOLOGIES ........ 25
FIGURE 2-14 REFERENCE PROCESS OF WORK- AND INFORMATION FLOW ........ 28
FIGURE 2-15: TYPE OF INSTALLED ERP SYSTEMS IN 2015 / 2016 ' ........ 29
FIGURE 2-16 THE SCOPE OF ADVANCED ROBOTS ........ 30
FIGURE 2-17 ROBOTS IN AUTOMOTIVE / GENERAL INDUSTRY IN 2014 ........ 31
FIGURE 2-18 IIWA BY KUKA ........ 32
FIGURE 2-19 CO-WORKING ROBOT AT LINE AT BMW PLANT ........ 32
FIGURE 2-20 ASSISTANCE ROBOT AT AUDI ........ 33
FIGURE 2-21: INDUSTRIES LIKELY TO BENEFIT FROM ROBOTS ........ 34
FIGURE 2-22 DEVELOPMENT OF SENSOR PRICES AND COMPUTING SPEED ........ 35
FIGURE 2-23PASSIVE RFID TAG ........ 36
FIGURE 2-24 RFID SYSTEM ........ 36
FIGURE 2-25 GLOBAL AVERAGE FACTORY SELLING PRICE OF RFID TRANSPONDERS (EXTRAPOLATED TO 2015) ........ 37
FIGURE 2-26: SCHEMATIC AM PROCESS ........ 40
FIGURE 2-27: TEMPERATURE SENSOR HOUSING ........ 43
FIGURE 2-28 FUEL NOZZLE ........ 43
FIGURE 2-29 AM MANUFACTURED PALLET FOR THE PRODUCTION ........ 44
FIGURE 2-30 PARADIGMS OF AM ........ 44
FIGURE 2-31: VIRTUALITY CONTINUUM ........ 45
FIGURE 2-32 DAQRI AR HELMET ........ 47
FIGURE 2-33 KNAPP KISOFT WEBEYE ........ 48
FIGURE 2-34: AR - BMW ........ 48
FIGURE 2-35 MR AT EMBRAER FOR PRODUCT DESIGN, REVIEW AND EVALUATION ........ 49
FIGURE 2-36 APPLICATION AS A PLATFORM ........ 52
FIGURE 2-37 RESULT OF BITKOM STUDY (N=559 / 100+ EMPLOYEES) ........ 54
FIGURE 2-38 OPINION AND ADVANCEMENTS ABOUT / OF I4.0 ........ 57
FIGURE 2-39 I4.0 PROGRESS ........ 58
FIGURE 2-40 READINESS MEASUREMENT IN DIFFERENT CATEGORIES BY SIZE OF COMPANY ........ 59
FIGURE 2-41 DEPARTMENT OF IMPLEMENTATION ........ 60
FIGURE 2-42 SPECIFIC IMPLEMENTATION OF I4.0 PROJECTS ........ 61
FIGURE 2-43 GARTNER'S HYPE CYCLE OF EMERGING TECHNOLOGIES 2015 ........ 62
FIGURE 3-1 TECHNOLOGIES IMPLEMENTED AND AFFECTED ACTIVITIES ........ 75
FIGURE 4-1 ATT + RA-XE WELDING LINE BY EVG ........ 78
FIGURE 4-2 EXEMPLARY PRODUCTS PRODUCED BY THE MACHINES OF EVG ........ 78

Figure 4-3 Sequence of the Process Optimization Procedure ........ 79
Figure 4-4 Tasks of the machine operator (1) ........ 84
Figure 4-5 Tasks of the production manager / administration (1) ........ 84
Figure 4-6 Tasks performed by maintenance personal (1) ........ 85
Figure 4-7 Tasks performed by maintenance personal (2) ........ 85
Figure 4-8 Tasks performed by maintenance personal (3) ........ 85
Figure 4-9 Tasks performed by machine operator (2) ........ 86
Figure 4-10 Tasks performed by machine operator (new1) ........ 91
Figure 4-11 Actions performed by platform (new1) ........ 91
Figure 4-12 Tasks performed by the production manager (new1) ........ 92
Figure 4-13 Tasks performed by MP (new1) ........ 93
Figure 4-14 Tasks performed by MP (new2) ........ 93
Figure 4-15 Tasks performed by machine operator (new2) ........ 93
Figure 4-16 Reaction time reduction ........ 96

# List of tables

TABLE 2-1 OVERVIEW OF ADDITIVE PROCESSES ........ 40
TABLE 3-1 OVERVIEW ABOUT THE COMPANIES ........ 66
TABLE 4-1 MACHINE PARK EVG ........ 81
TABLE 4-2 PDA - MACHINE FAILURE - DATA SET ........ 87
TABLE 4-3 PDA - MP ASSIGNED - DATA SET ........ 87
TABLE 4-4 AVERAGE REACTION TIME ........ 88
TABLE 4-5 ESTIMATED COSTS FOR IMPLEMENTING NEW SYSTEM ........ 90

# 1 Introduction

The increasing digitalisation of the world has already affected most parts of our lives. On an everyday basis we are confronted with our smartphones, laptops, tablets or similar devices. Communication and sharing information is one of the basic pillars for a successful collaboration nowadays. Today most of this communication is done over the internet. But these developments are not only limited to the private sector. The advent of those developments in the modern information and communication technologies also took place into other segments like the technical world, the medical industry, retailing business and many other industries in our world.

This work is focusing on the manifestations of the digitalization concerning the technical world. One of the most promising and interesting initiatives the manufacturing industry encountered during the last years in the context of digitalization was and still is the so called fourth industrial revolution also known as Industry 4.0.

The first revolution being the mechanisation in the 18$^{th}$ century using hydropower and steam power to support the manufacturing processes, the second being the start of mass production supported by electrical energy and the third revolution was introducing information technologies (IT) and electronics to increase the degree of automatization.[1]

The term Industry 4.0 (I4.0) was introduced to the public at the Hannover Messe back in 2011.[2] It subsumes the different technologies and concepts developed over the last years with the idea of introducing Internet and Communication Technologies (ICT) into the industrial sector. The motivation for doing so is based on the recent developments in the manufacturing sector. The increasing competition due to globalized markets and the customers' desire for more and more individualized products in combination with shorter product lifecycles have been identified as the main drivers.[3]

The scope of the initiative I4.0 is enormous and therefore the investigated area will be narrowed down to the production environment in the discrete manufacturing sector and the respective technologies within. In this sector the potential applications can be identified all along the lifecycle of a product influencing each part of the value generation chain.

[1] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 13
[2] Kagermann, H.; Lukas, W.-D.; Wahlster, W. 2011, P. 2
[3] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 5

## 1.1 Objectives

The main objective of this thesis is to realize the implementation of one specific I4.0 measure carrying out a real use case. Additionally, the status quo of the degree of implementation regarding the most prominent technologies concerning I4.0 is determined.

The first objective of the literature review therefore is to clarify the term I4.0 and its relation to other similar initiatives currently around. The next objective is to determine the most promising and popular I4.0 technologies and concepts that will be or are already implemented in the production environment of the discrete manufacturing sector. Subsequently already applied use cases for the different technologies should be identified showing their practical applicability. Finally, the accompanying benefits as well as the hurdles arising while implementing those technologies will be presented.

The goal of the expert interviews is to gain insights of the current implementation status in Austrian companies and to evaluate the findings of the literature review. During those interviews the applicability of the applications in the respective industry sectors will be discussed. The experience and knowledge the companies gathered during the implementation process should also help to evaluate the preceding findings.

The objective of the last part of this work is to optimize a process using digital technologies at a company that has made no experience in I4.0 so far. The real world applicability of the so often just theoretically discussed revolutionary digitalization of the manufacturing industry should be shown.

## 1.2 Methodical approach

In the first section of this thesis the term I4.0 is specified reviewing the latest publications and studies. In addition, the statements of experts regarding this topic will be analysed as well. Due to the fact that currently several different similar initiatives are pending, this specification will lead to a clear definition of the investigated area.

Subsequently the reasons which led to the necessity of this ongoing paradigm shift in the manufacturing sector are investigated. In this section the previous developments in industry will be presented and the claims which have to be met in the future will be discussed. This should show the importance of this initiative and unveil the potential impact it might have.

After a comprehensive literature review the underlying concepts for a successful and sustainable implementation of I4.0 should be determined. A revolutionary change like the one this initiative is striving for has to have an overarching goal towards all the affected parties should head. Therefore, they should follow a conceptual framework how this goal should be achieved. The determination of the basic pillars of this framework will present the target state and clarifies the measures to take for achieving this status.

The next section should present the different technologies and some of the already applied use cases. This is done to identify the technologies that are the most relevant in the context of I4.0 and how these might be applied in practice by referring to real use cases. The challenges arising while implementing these technologies will also be investigated to demonstrate which factors are hindering a widespread distribution of those technologies.

In the final section of the literature review the general hurdles, problems, benefits and the expectations of the near future developments regarding the implementation of I4.0 will be examined. This should present how manufacturers see the recent developments and which obstacles they are facing today as well as the expectations they have when the identified challenges should be overcome in the future.

In the first phase of the empirical part expert interviews will be conducted. The objective is to get further insights from practitioners. The experiences and know how they gathered during the implementation of I4.0 measures at their site should help to evaluate and support the findings of the literature review.

In the last part of this thesis the findings of the work so far should be used to support the implementation process of I4.0 measures in a real use case. Therefore, a company not having any specific I4.0 measures implemented until now, will be chosen. This part should demonstrate how the findings from theory could be transformed into practice and should show the potential even small I4.0 measures can have.

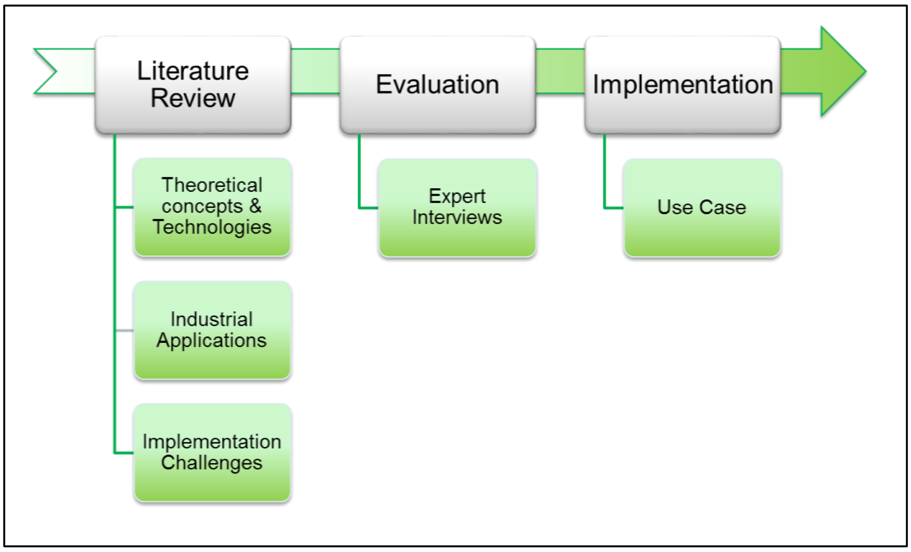



*Figure 1-1 Methodical Approach*[4]

[4] Own representation

## 2 Literature Review on Industry 4.0

Industry 4.0 is the term used for the currently ongoing transformation and digitalization of the industrial world we see today. Over the last 40 years the IT has brought radical transformations successfully employing ICT into all the different areas. Those transformations especially affected the industrial manufacturing processes where approximately 90% of all the processes are supported with ICTs. The evolution of the Personal Computer into smart devices with the accompanying ongoing proliferation of the internet as well as the trend to more and more powerful and autonomous microcomputers embedded in almost anything are leading to a more connected world than ever before. The resulting equipped things are, respectively will be able to communicate, store and transfer information and are therefore creating a new form of the internet, the so called internet of things, consisting of so called cyber physical systems (CPS).[5]

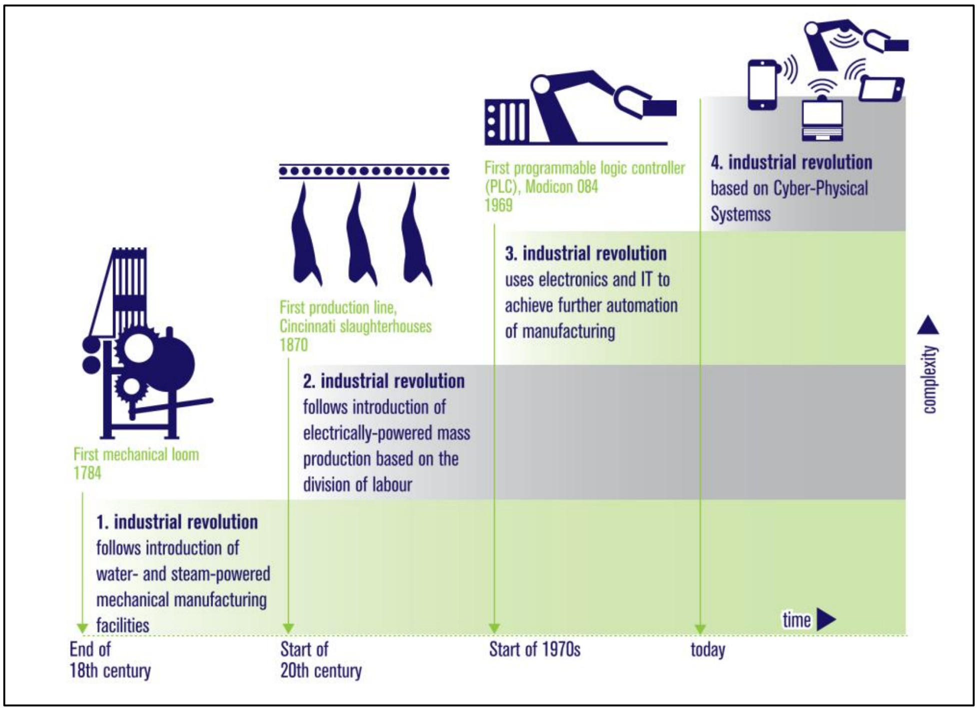



*Figure 2-1 The four steps of industrial revolution*[6]

Figure 2-1 represents the four steps of the industrial revolution with the according time of occurrence. Beginning in the 18th century with the introduction of water- and steam-powered machines supporting the manufacturing equipment. The second industrial revolution was empowered e.g. Henry Ford refining the assembly line enabling cost efficient mass production. In the 1970s the first programmable logic controller was introduced into the industrial environment and completely changed the industrial landscape back then, a development that is now designated as the third industrial

[5] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 13
[6] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 13

revolution. Today we can experience the fourth industrial revolution enabled through CPS which are again transforming the landscape of the industry today. A detailed look on what CPS' are is presented in chapter 2.6.1.

## 2.1 Industry 4.0 as Successor of the Internet of Things

Probably first used was the term Internet of Things (IoT) as the title of a presentation from Kevin Ashton in 1999 at Procter & Gamble in which he linked the back then upcoming topics of the radio frequency identification (RFID), the supply chain management and the internet. His philosophy behind the IoT was the ability of things to record their environment 24/7 without the interaction of humans. The self-recorded data of the equipped things would enable tracking everything at any time, and could therefore reduce greatly waste, loss and costs. It would be automatically known when things needed replacing, repairing or recalling.[7]

12 years later, in 2011, at the *Hannover Messe*, the *Verein Deutscher Ingenieure* (VDI) went public with the initiative called *Industrie 4.0.* The main idea of it is to stay competitive in a high wage country like Germany. Through the connection of machines and industrially produced goods a digital betterment should be realized. A bridge between the real world and the virtual respectively the digital world realized with the introduction of CPS should be created. Instead of the centralized control system the product itself should be able to find its way through the production and tell the machines which tasks should be performed on it. All relevant information of the production process should be stored on the product and even after shipping it to the customer additional information of the individual use of the product could be stored to be able to predict and therefore fulfill the future requirements and desires of the customers with the next generation of the products.[8]

## 2.2 Internet of Things vs. Industrial Internet vs. Industry 4.0

In the following section the different initiatives often used synonymously will be explained.

Figure 2-2 represents the overarching aspects of the IoT concept in relation to the industrial internet respectively I4.0. The IoT subsumes in parts the other two concepts and is extending the Industrial Internet in terms of reach by the elements which are affected by it. The concept of the IoT, in contrast to the industrial internet, also considers people as connected to the internet using wearable devices capable to constantly record, store and share information. An example for this would be a Smart Watch or other activity tracking devices.

I4.0 on the other hand is extending the IoT in terms of what is altered by the concept and includes technologies like 3D printing, augmented reality and others relevant for the production processes. But in terms of reach, like who is impacted by the concept, the IoT

[7] Ashton, K. 2009, P. 97–114
[8] Kagermann, H.; Lukas, W.-D.; Wahlster, W. 2011, P. 2

is more comprehensive when compared to I4.0. Reasons for this are the scope of applications in sectors like the so called *Smart Homes*, *Smart Grids* and so on and is therefore also including other applications based on the connectedness provided through the internet and is not limited to industrial applications. The reach of the IoT also affects areas like hospitals, public transportation, cities, retailing, households and everything else which can be or already is in a way connected.

The Industrial Internet, a term introduced by General Electrics, one of the main players in the context of increasing digitalization in industrial applications, especially in the US, can be seen as a sub-field of I4.0. It is focusing more on the software components and the connectedness of machines and other industrial devices and not mainly dealing with the production technologies like I4.0 is.

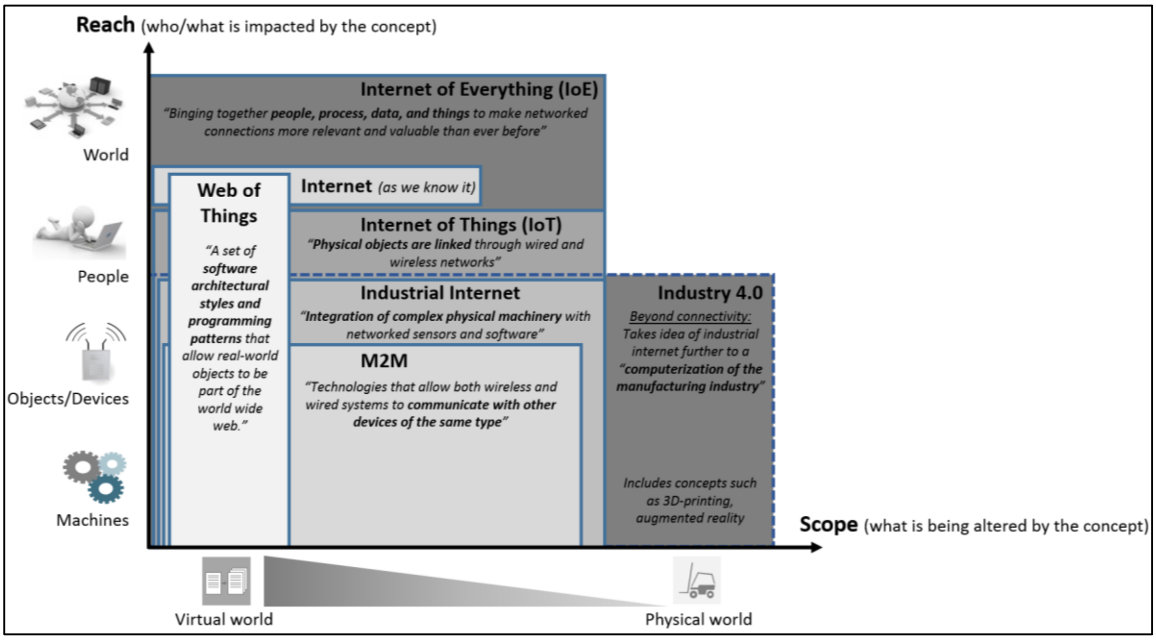



*Figure 2-2 Scope and Reach of different internets*[9]

In general, I4.0 is a term used for the recent developments regarding the production and value creation systems through the connection of the real and the digital world.[10]

I4.0 is a concept which should help to empower the industrial sector to reach the next level. The term Industry 4.0 is mainly used in the European region whereas the term Industrial Internet is often (wrongly, when looking at Figure 2-2) used as a synonym for I4.0 in the English speaking regions.

[9] *Lueth, K. L. 19.12.2014*
[10] Bischoff, J. 2015, P. 116

## 2.3 Reasons for Industry 4.0

In the following section the historic reasons that initiated the start of the initiative I4.0 as well as the challenges accompanying the ongoing developments and the arising trends that will shape the future will be investigated.

### 2.3.1 Histroic justification

The justification or even the necessity for I4.0 can be found in the developments the production environment was experiencing over the last 40 to 50 years. Beginning in the 1970s the concept of Lean, which bases on the Toyota Production System, was introduced to the western world and there it was widely implemented. After the concept was implemented and the benefits accompanying it were to some extent exhausted the industry established new performance enhancer like outsourcing and offshoring in the 1990s by moving low skill production to low cost and therefore low wage countries. Since the 2000s those advantages too are shrinking due to the fact that the wages in these countries are rising and fright costs and tolls are increasing.[11]

The automation of labor was the final step so far and now the industry is looking for a new path leading to higher operational effectiveness. I4.0 is promising these new cost savings and potentials in increasing process efficiency that have so far remained untapped.[12]

Beside the historic developments also the megatrends which will be shaping the future dictate the need for new innovations and will be investigated briefly in section 2.3.2.

### 2.3.2 Future necessity

In Figure 2-3 the megatrends influencing the manufacturing industries over the next decades are shown which were identified by Abele, Reinhart 2011 who was analyzing several studies and publications. Those trends have, according to the studies and publications they were developed from, a high probability of occurrence. In the short term they are of course often overlaid by temporary events like crises but in the long term they will be the main driver for change for the organizational tasks, technical issues, qualifications and general working conditions. On the left side of this figure are the trends influencing the way how products are produced like the trend of ongoing globalization. On the right side the trends influencing the requirements on and types of products are shown.[13]

The concepts of I4.0 also addresses elements besides the production, meaning that the potential of productivity gains particularly lies in the improvement of the decision making processes and improved brain-work.[14]

---

[11] Wee, D. et al. 2015, P. 11
[12] Wee, D. et al. 2015, P. 19
[13] Abele, E.; Reinhart, G. 2011, P. 11
[14] Schuh, G. et al. 2014, P. 51

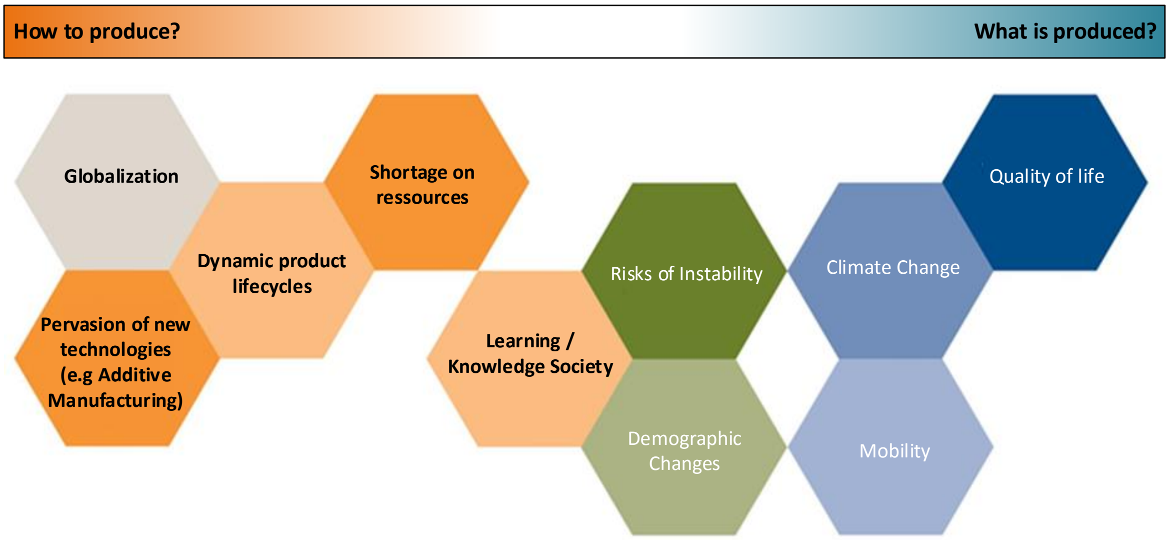



*Figure 2-3: Megatrends of future production[15]*

A brief explanation of the different trends according to Abele and Reinhart affecting the future of production will be given in the following section: [16]

#### *2.3.2.1 Globalization*

The globalization represents the trend of the increasing worldwide interdependencies in areas like politics, economics, culture and others where different levels like individual companies, corporations or even whole states are being in pronounced interrelation to each other. Subsumed under the segment of economic globalization is the increase in global trading, the creation of cooperations and enterprise networks as well as the increase in direct foreign investments.

The main reasons for the already previously mentioned outsourcing of production capacity are the labour costs, market exploitation, expanding capacity and major customers. [17]

The attractive markets in the BRIC (Brazil, Russia, India and China) states, the increase of productivity of foreign production sites and the decreasing transportations costs as well as the connectivity provided by the internet will keep this trend going for the next time.

#### *2.3.2.2 Pervasion of new technologies*

With this trend the interconnectedness of the different scientific disciplines is attracting attention. One reason for this trend is that innovations occur more and more at the interfaces between different specializations and cannot be directed to one specific field. Another aspect is the increasing complexity of the specific fields in combination with the increasing extent of available knowledge in the individual fields. For example, the

[15] cf. Abele, E.; Reinhart, G. 2011
[16] Abele, E.; Reinhart, G. 2011, P. 11–24
[17] Kinkel, S. 2009, P. 31

integration of mechanics, informatics and electronics in a passenger car shows the intensity of this interdisciplinary cooperation and this trend will even intensify in the future.

#### *2.3.2.3 Dynamic product lifecycles*

The increasing dynamic of the products lifecycles addresses the steadily declining time between two generations of a product. Disruptive changes in the applied technology used in the former generation of a product is one element that substantiate this trend. The customers call for more customizable and individual products and that also effects the claims on technologies and logistic solutions in the manufacturing industry.

#### *2.3.2.4 Shortage of resources*

The growing global population, the increase in the standard of living and the sometimes careless use of the available resources result in a high resource consumption. Due to the fact that the resource deposits are not endless it is clear that some of these resources like neodymium might soon be exhausted which calls for improved recycling processes and closed resource loops.

#### *2.3.2.5 Learning / knowledge society*

The constant pressure form the market and the competitors leads to a lot of innovations and all these innovations come along with new knowledge. Education and knowledge are seen as key resources for social and economic progress especially in countries with a lack of natural resources like Germany and Austria. In economies like these education and innovation are the main factor guaranteeing future wealth.

#### *2.3.2.6 Risk of instability*

Instability in this context describes the difficulties coming along with an increase in market and economy dynamics as well as safety and security risks of interlinked financial economies and enterprises. Anticipating future developments with a sufficient probability of occurrence is becoming more difficult nowadays. This problem can only be faced with flexible production systems and networks and with advanced capabilities in forecasting technologies.

#### *2.3.2.7 Demographic changes*

The trend of demographic changes represents the changes in age distribution which can be perceived especially in developed countries. The declining birth rate in combination with the increasing life expectancy lead to an overaged society with the result of a lower working population not mentioning the expectations for the classification of the individual workers. The lack of specialist workers is already a problem today for the different industries and therefore new innovations to overcome these deficiencies need to be developed.

#### *2.3.2.8 Climate change*

On the one hand the climate change calls for more efficient production strategies to increase the efficiency of the production in relation to the $CO_2$ emission. On the other hand, the international restrictions open up a wide field for the so called green and sustainability sector.

#### *2.3.2.9 Mobility*

Mobility is a basic need and therefore not only the individual transportation but also the transportation of goods will increase tremendously in the next years. From the manufacturing point of view this means two things. The first is the increasing demand for transportation equipment. Secondly, also the coordination of the movement of goods needs to be considered where not only the costs for transportation but also the availability and climate goals need to be met.

#### *2.3.2.10 Quality of life*

The final trend, the quality of life, represents the central topic of how to stay healthy even in times when an older age is reached when considering the demographic changes like previously mentioned. Production technology and production science can contribute to this field in several ways. One element is to ensure and protect healthy working conditions as well as an improved work-life balance. Another approach is to make innovations in the health sector accessible to the general public as well as individual treatments for each patient. Besides this, innovations in health sciences should become producible in a more efficient way in terms of costs and for example materials.

## 2.4 The Potential Impact of the Internet of Things

The Mc Kinsey Global Institute, part of the well-known consulting company McKinsey & Company, published an article in June 2015 containing estimations about the potential impact of the IoT on the different sectors which can be seen in Figure 2-4. The settings in the figure are representing a broader view to get a bigger picture of the different effects of the IoT because often different sectors are overlapping. Therefore, instead of focusing on businesses and markets different settings were investigated. E.g. when looking at an automaker you could identify the improved manufacturing efficiency and the resulting reduction in costs but you couldn't capture the beneficial use of sensors in the car collaborating to improve the traffic situation in cities which can also have a huge impact.[18]

[18] Manyika, J. et al. 2015, P. 2

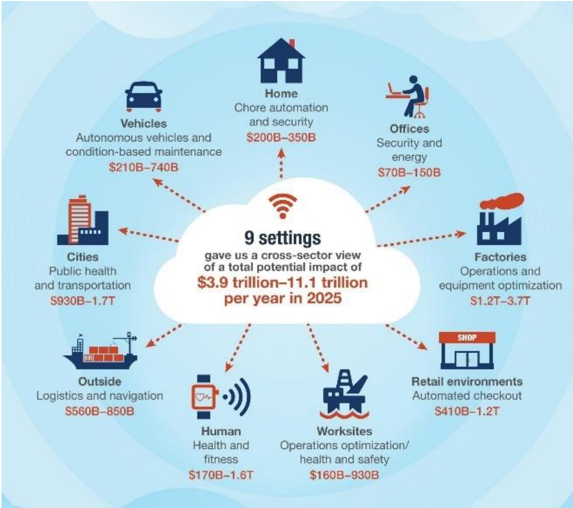



*Figure 2-4: The scope of IoT*[19]

## 2.5 Industry 4.0's Potential Impact

The biggest influence might be expected in the factories with an estimated potential economic impact of 1,2 – 3,7 trillion US dollars per year in 2025. Elements included in the factories setting are places with repetitive work routines including hospitals and farms, places where operating efficiencies can be achieved as well as the optimized used of equipment and inventory. In addition to the factories sector, parts of the economic impact of the settings worksites, outside, vehicles and offices can be added because they also play a significant role in the industrial sector.[20]

Based on this research the greatest potential of the IoT in the industrial sector will be the optimization of operations and making the different processes more efficient. Sensors will be used to adjust the performance of machines best to the current conditions and data from production machinery is used to adjust work flows instead of human judgment. This is realized by remotely tracking, monitoring and even adjusting machinery based on data from different locations of the plant and even across plant and company boarders. The I4.0 optimizations in operations have the potential to create additional revenue for IoT applications of $633 billion to $1,8 billion per year in 2025.[21]

## 2.6 The Basic Concepts

I4.0 is often, wrongly, reduced to the solely implementation of new technologies. The real benefits I4.0 is holding can only be lifted by the combination and connection of those technologies using networks to share information along the whole value generation network. The following basic concepts have been identified as those who are the most

[19] Manyika, J. et al. 2015, vii
[20] Manyika, J. et al. 2015, P. 8
[21] Manyika, J. et al. 2015, P. 66

relevant for the production environment after analyzing the *recommendations of implementing I4.0* presented by the *Plattform Industrie 4.0:*[22]

- Vertical and Horizontal Integration
- Consistent Engineering
- Cyber physical systems

Other concepts mentioned in this framework like training and continuous development of the employees and workers, the broadband infrastructure, the reference architecture for standardizing the IT architecture as well as the work organization and design, the legal framework or the resource efficiency and so on have not been considered in this thesis due to the minor current relevance to the shop floor technologies being the main topic addressed in this work.[23]

In addition to these three concepts another important element, the concept of decentralization has been identified by Roth, A. 2016. Although the decentralization is also mentioned recurrently in the framework provided by the *Plattform Industrie 4.0*, it has not been allocated with much attention there. The capability of making decentralized decisions due to distributed intelligence and being able to shift from a single centralized control instance to numerous decentralized units was first mentioned as an additional fundamental concept in this publication and is of major importance to fully leverage the benefits accompanying I4.0.[24]

These four concepts are the basic pillars that need to be established for a successful implementation of I4.0 and are needed to lift the full potential substantially. In the following section an explanation of the terms will be given to understand why these fundamental prerequisites have this importance.

### 2.6.1 Cyber Physical Systems

ICTs include most of the main drivers of innovation. In the context of I4.0 two of them are especially relevant. One of the drivers being embedded software systems which are typically found in all high tech products today. Their functionally is directly developed to support those products. The other driver is the existence of global networks like the internet. If these two elements are merged together CPS can result. The current interaction of the equipped objects with the physical world using sensors and actuators is developing towards a level where these systems are opening up and start to be connected to each other, are able to communicate and therefore create a new network of CPS which can be supported by the internet and would therefore be forming one element of an overall IoT.[25]

[22] Kagermann, H. et al. 2013, P. 16–30
[23] Kagermann, H. et al. 2013, P. 5–7
[24] Roth, A. 2016, P. 39–41
[25] Geisberger, E. et al. 2011, P. 11

In Figure 2-5 a schematic representation of the two basic elements a CPS exists of is shown. One is the digital component. It is including the embedded systems and the technology to provide the connectivity to the internet as previously mentioned. The systems in the digital component monitor the current status of the physical object, representing the second component, via sensors. The parameters provided by those sensors are then processed inside the digital component and the resulting necessary actions are then performed by the actuators manipulating the physical object. Additionally, to the decentralized actions performed locally at the CPS the physical object can still be manipulated directly due to human interaction. Another way of human to object interaction can be performed using the different user interfaces where the parameters representing the current state of the physical object can be influenced via the digital component. [26]

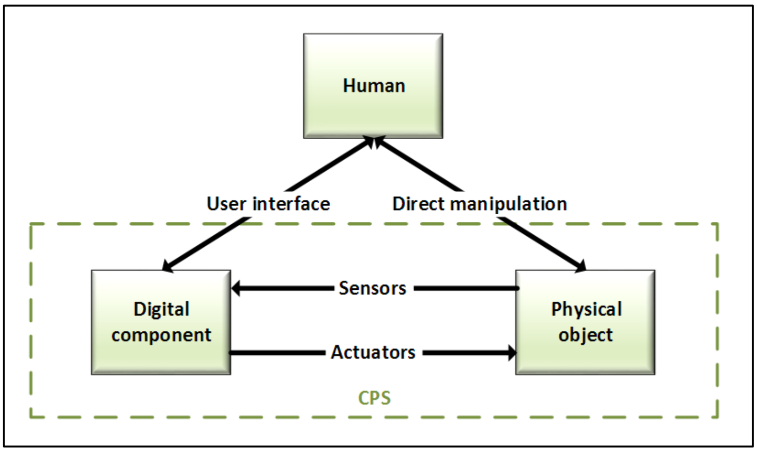



*Figure 2-5 Elements of a CPS[27]*

Lee, J.; Bagheri, B.; Kao, H.-a. 2015 developed a more practical approach which is not as general as the description above but it should represent the sequential workflow manner of how to construct a CPS. They call it the 5C architecture of a CPS which will be explained here briefly:[28]

1. Connection: To acquire accurate and reliable data of the desired objects data has to be collected. This can be done using sensors or gathering data from the manufacturing software like the manufacturing execution system (MES), supply chain management (SCM) system or any other available data source. Two factors have to be considered: Data collection of various data types and their real time critical transfer to the servers.
2. Conversion: Meaningful and valuable information has to be extracted from the collected data. In the recent years a special focus has been set to the analysis of this

[26] Bauernhansl, T.; Hompel, M. t.; Vogel-Heuser, B. 2014, P. 525
[27] Bauernhansl, T.; Hompel, M. t.; Vogel-Heuser, B. 2014, P. 525
[28] Lee, J.; Bagheri, B.; Kao, H.-a. 2015, P. 19–20

data and algorithms have been developed to identify the status of an object and therefore creating self-awareness.

3. Cyber: This level acts as a hub where all the information gathered from the equipped objects is pushed to and doing so a network of objects is formed. With all this information additional insights can be generated. Objects can be compared to others and benchmarks for the different objects can be generated. This huge amount of data can also be used to make predictions about the future developments of the objects.
4. Cognition: Represents the proper presentation of the knowledge gathered in the previously mentioned *Cyber* level to expert users which supports their decision making process with the latest information.
5. Configuration: This level represents the feedback from the cyber space to the physical space. It can be seen as the supervisory control to make the objects self-aware and self-adaptive. This level acts as control system to apply the correct decisions which have been made in the cognition level.

Figure 2-6 shows the 5C levels of a CPS enabled factory with machine tools as the possible practical implementation.

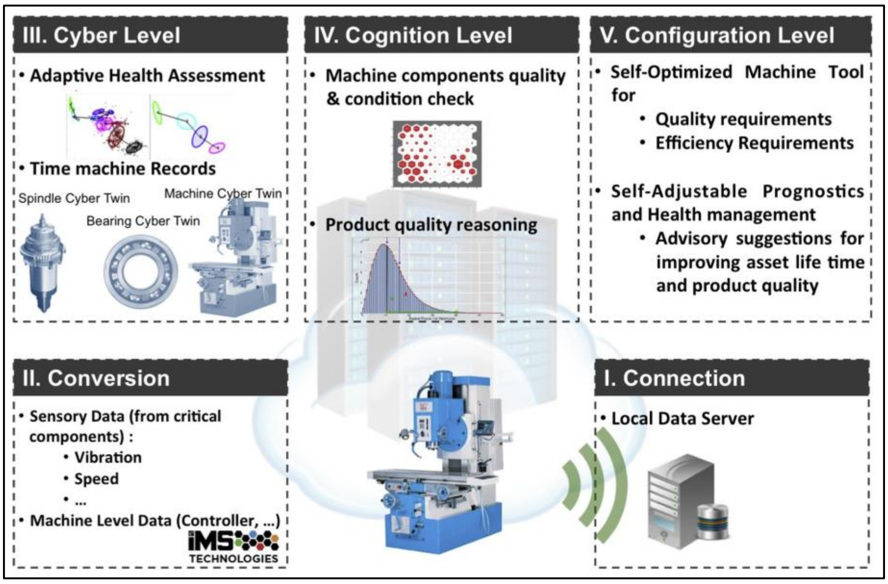



*Figure 2-6: 5C CPS structure of a tool machine*[29]

## 2.6.2 Vertical and Horizontal Integration

Vertical integration represents the interconnectedness of the different levels inside a company. For its visual representation the automatization pyramid is adduced frequently (Figure 2-7). The objective is to connect the different levels where relevant information is generated and therefore the according IT systems need to be linked to enable a consistent connection from the shop floor up to the corporate management level. This has already

[29] Lee, J.; Bagheri, B.; Kao, H.-a. 2015, P. 22

been mentioned in a previous initiative called computer integrated manufacturing (CIM) back in the 1970's. The enormous effort it takes to connect the different systems due to the lack of standardized interfaces inhibited its implementation so far. For I4.0 this means that one basic prerequisite is the standardization of the interfaces between the different levels to enable this effortless flow of information along the different hierarchy and activity levels.[34]

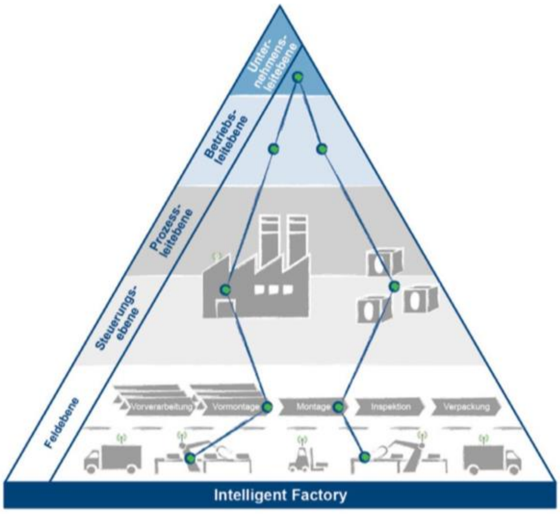



*Figure 2-7: Vertical Integration - Automatization Pyramid[35]*

The main focus of the horizontal integration in the context of I4.0 is the collaboration along the whole value generation chain inside and beyond the company boarders. The integration of all the different IT systems at all stages needed for the support and the execution of the different value creation activities is the essential element for a consistent solution. To be able to share the information gathered along the entire value generation process, a sophisticated network needs to be established where all necessary information can be shared instantly and without any further effort.[36]

For the horizontal integration three elements have to be considered. The first element is the interconnectedness of the individual production systems to one production network inside the company (Smart Planning). The second element is the integration of all partners along the supply chain upstream (Smart Sourcing). The third and last element considers the integration of the customer regarding his requirements and additionally providing him with information about the order and delivery status (Smart Distribution). These three elements and their allocation in the automatization pyramid and the affected levels can be seen in Figure 2-8.[37]

[34] Plaas, C. 2015, P. 8–9
[35] Plaas, C. 2015, P. 8
[36] BITKOM e.V.; VDMA e.V.; ZVEI e.V. 04/2015, P. 16
[37] Plaas, C. 2015, P. 9

The integration of all these partners into one consistent system enables the allocation of the right information at the right time. The according actions can then be initiated to optimize the whole value chain driven by the optimal decision making process based on all the information which is relevant for best fulfilling the processes according to the superordinate goals and requirements.[38]

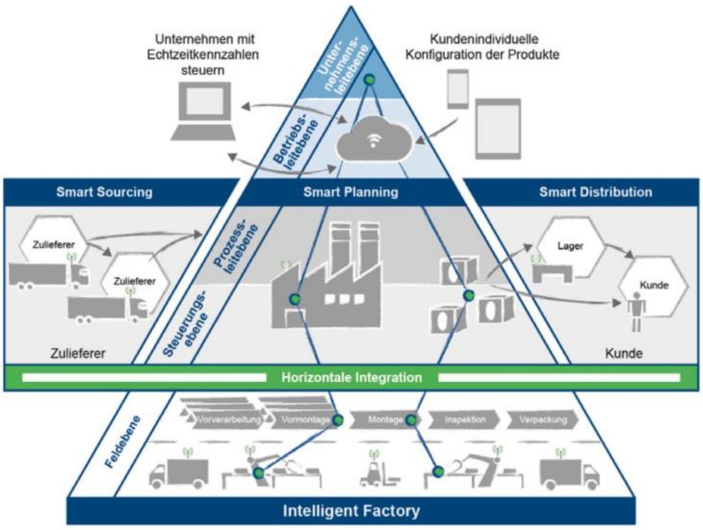



*Figure 2-8: Three elements of the horizontal integration[39]*

## 2.6.3 Consistent Engineering

Consistent engineering means the integration of all the data gathered at the different IT systems along all phases of an objects lifecycle into one consistent system. A holistic view about the respective object along all the different disciplines and stages of this objects "life" can then be established.[40]

The lifecycle of a product starts with the development of the product and the engineering process of the according production system. The next step is the production of the product realized by the previously engineered production system. The following phase is the use of the product and at its end is the recycling and the dismantling process. All information gathered along this lifecycle should be connected and stored.[41]

Figure 2-9 shows the different stages from a digital to a physical product and the respective IT systems and services connected to those stages. The product lifecycle management (PLM) system is in this case is the overarching system that combines all the information generated by the subsystems along this path. Consistent engineering calls for the standardization of IT interfaces and should enable the possibility to access always the latest

[38] BITKOM e.V.; VDMA e.V.; ZVEI e.V. 04/2015, P. 16
[39] Plaas, C. 2015, P. 9
[40] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 35–36
[41] BITKOM e.V.; VDMA e.V.; ZVEI e.V. 04/2015, P. 23

information out of one single system. This approach should reduce data silos and try to summarize the digital as well as the physical information.

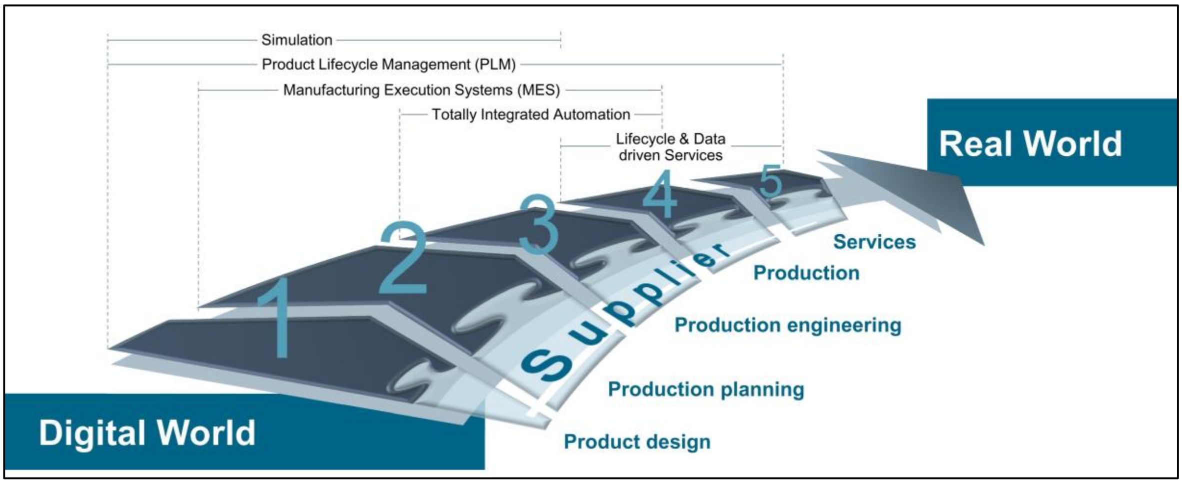



*Figure 2-9: Digital to physical world*[42]

Most of the information along the lifecycle of an object is already available today and to some extent PLM systems are already introduced capturing this information. The novelty in the context of I4.0 is that a so called single source of truth has to be established where all the information is automatically stored. Every part of information generated during an objects lifecycle is located at one single location and any sort of ambiguity can therefore be precluded. The information concerning the individual objects is directly stored and connected to the unique identity of the object. This leads to the crucial link between the object and the respective information concerning the object.[43]

The integration of new digital information into the superordinate PLM systems or even the merging of the PLM system with the SCM tool are still the most challenging tasks. This can only be achieved through the standardization on the IT level leading to an effortless adaption of the tools, interfaces, methods and models into one overarching framework.[44]

### 2.6.4 Decentralization

Decentralization has to be considered at two different levels. One is the decentralization on the small scale in the form of distributing intelligence to many different objects and devices. In the manufacturing industry this means for example to equip the products, production equipment, and other elements of an assembly or even the raw material with sensors or other embedded systems which are capable of storing and sharing information and are able to communicate with other equipped devices or things in the entire network.[45]

[42] Helmrich, K. 2015, P. 10
[43] Schuh, G. et al. 2014, P. 52
[44] Bracht, U.; Geckler, D.; Wenzel, S. 2011, P. 338
[45] Roth, A. 2016, P. 39

The large scale level is combining all this spread intelligent devices into an overall unit making it a self-regulating and self-controlling production system. The objects could know their current parameters and could self-regulate their parameters by including a control loop which is capable of a quality control process with the respective evaluation and subsequent regulation between the actual and target figures. This is already realized on stand-alone machines and small machine networks using programmable logic controller (PLC) where sensors and actuators are connected via cables, but the true idea of decentralized control units is to include the whole production facility as well as other facilities even beyond the company boarders into this self-regulating process. Therefore, the centralized control cabinet housing the decision elements must be replaced by local, decentralized but connected decision elements who are forming a large network where each component can be influenced by its partners in the value generation chain.[46]

Decentralization also means that instead of precise working plans and instructions each element should optimize itself according to the target objectives prescribed by the upstream but taking also the downstream elements into consideration. The different elements in the process chain have a clearly defined scope they are responsible for and should be able to best fulfill their local requirements.[47]

### 2.6.5 Interdependencies of the Concepts

The four basic concepts that have now been presented represent the basic building blocks required to leverage the full potential of I4.0. CPS' are therefore the initial element all the other concepts are building on. Without the capability of storing information to the respective object, a consistent tracking and tracing throughout the objects entire lifecycle is not feasible. The presence of this information, including data about the objects history and its designated future, is crucial to enable a local and decentralized control of the processes. Those processes are then enabled to interact with the object according to the required activities which need to be performed on it. The decentralization requires the ability to communicate and share information in the network which is established through the capabilities provided by the digital component of the CPS. The superordinate principle of vertical integration including all partners inside the company and the horizontal integration which includes the partners along the value generation chain can only be sufficiently realized with the same standards and interfaces that the consistency of the IT systems should provide.

### 2.6.6 Requirements for Implementation - Standardization

The underlying basic concepts which are needed to be established to fully leverage the potential of I4.0 have been determined and explained in the previous chapters. To fully implement those concepts further progress in additional fields needs to be achieved.

[46] Roth, A. 2016, P. 40
[47] Bischoff, J. 2015, P. 116–117

Especially the standardization in IT regarding the interface compatibility of the different objects to enable the required advanced connectivity between those objects represent a major challenge.

The standards need to be based on a general consensus of all the partners involved in this paradigm shift and is crucial to establish a network capable of sharing the respective information. Due to the fact that international exchanges are increasing, the standardization is conducted on different levels. The several national institutes are suggesting the standards to European organizations which then have to transfer the national intentions to a level where a general European consensus can be found. The so far developed standardizations have furthermore to be discussed on an international level and have to include the intentions of other nations. The process of international standardization and some of the responsible institutions can be seen in Figure 2-10.[48]

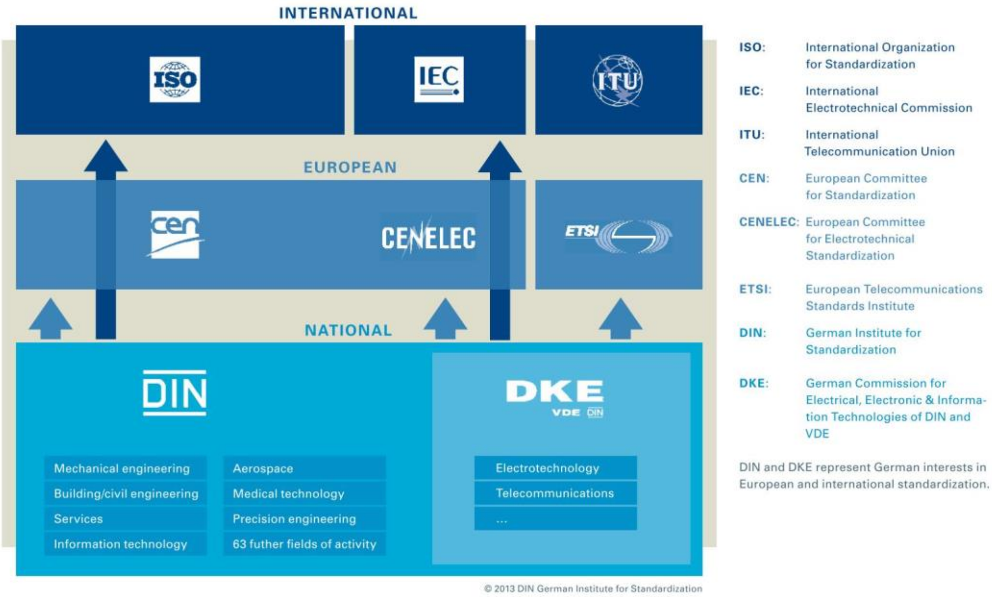



*Figure 2-10: Standardization Process[49]*

In most of the affected areas a large number of standards have been established in the past and have proven their applicability in practice. These different standards have to be integrated into one overarching, robust and more compact solution which is free from overlapping's.[50]

Due to the fact that this is a long lasting process which requires several iterations of approval, change requests and subsequent modifications a version on which the industry can rely on requires further progress.

48 Adolph, L. et al., P. 11
49 Adolph, L. et al., P. 12
50 Adolph, L. et al., P. 30

The benefits expected to come from I4.0 as well as the ongoing developments and trends mentioned in chapter 2.3.2 force the companies to take actions already today to be able to stay competitive. In literature specific technologies have been mentioned that should support I4.0 and are to some extent already applied in practice. These technologies will be investigated in detail in the following section.

## 2.7 Technologies Empowering I4.0

To identify the most relevant technologies empowering I4.0 the publications mentioned in the appendix (A2) were analyzed in detail. To extract the most relevant technologies for the current production environment they were listed and put into relation of their appearance. The result of this analysis is presented in Figure 2-11.

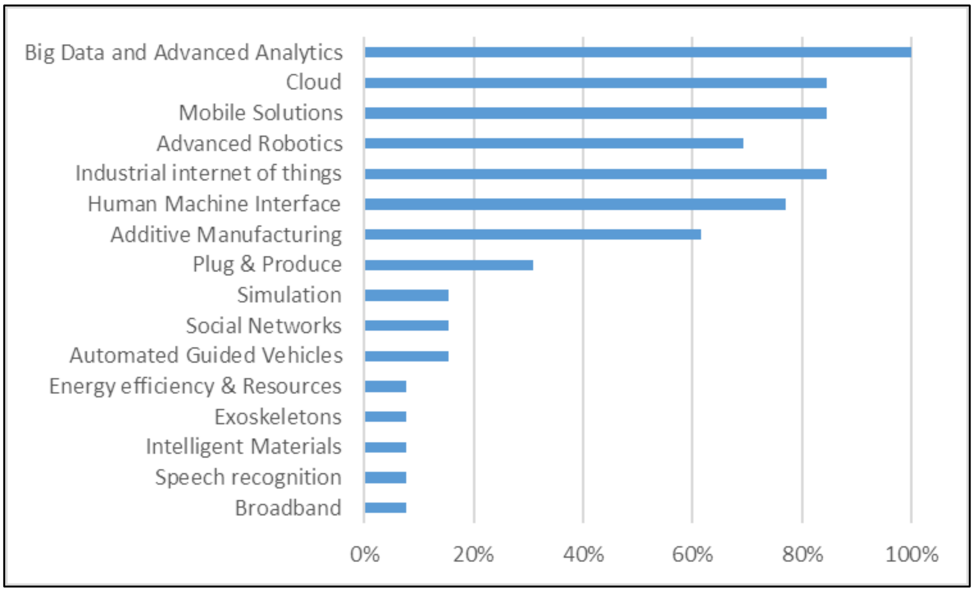



*Figure 2-11 Relevant Technologies*[51]

As the representation shows there is a big gap between the first seven technologies which are all mentioned in 60% or more and the other technologies mentioned inconsistently in the investigated publications. According to these results the constantly reoccurring technologies can be specified as the most relevant and are therefore investigated in more detail in the following section.

### 2.7.1 Big Data and Analytics

In 2001 Doug Laney was the first who characterized Big data by the "3V" (volume, variety and velocity). Volume in this case stands for the increasing amount of data that is generated and has to be treated per time period, variety represents the heterogeneity of the data and velocity addresses the frequency of data capturing and the requirements for

[51] Own representation

the processing speed. If these three factors exceed the normal extent this kind of data is called Big Data.[52,53]

Often additional "V's" are added to the previous mentioned three. One particular is veracity. Its characteristic represents the correctness, completeness and reliability of the data. It is especially used in combination with data where the value cannot be seen or measured directly. A prominent example for this type of data is social media data like user generated text. This text is often coined with subjective feelings and different temporal and content related context which can be used if analyzed correctly.[54]

Data in general is created at an ever-increasing rate. Besides the data generated by phones, in social medias, imaging technologies for medical diagnosis and others, sensors and other devices automatically generate diagnostic data that needs to be stored and processed. In the best case the analysis of it happens in real time to be able to generate value on time. Keeping up with this huge influx of data is difficult, but even more challenging is analyzing that vast amounts, especially when this data is not available in traditional notions of data structure because more and more unstructured data is generated.[55]

According to current estimations about 80 to 85 % of the data is unstructured or semi structured data. Unstructured being text or other multimedia data where semi structured data can be log files generated by machines. Structured data on the other hand are e.g. spread sheets and other lists with clearly identified data sets. Consequently, a large part of the data available can only be used after complex transformations.[56]

Conventional storage and processing of Big Data is not possible with traditional IT systems and the corresponding IT architecture. Data and especially Big Data can be seen as the foundation for innovative value creation and is therefore considered as the resource of the future.[57]

To actually become the resource of the future, the vast amount of data needs to unveil the desired information to be able to draw the right conclusions and correlations. That's why after collecting and storing, data analysis is the third pillar relevant to get the benefits expected by Big Data. To transform Big Data into Smart data, advanced analytics are the necessary tools.

Data is only becoming useful if it is processed in a way that provides context and meaning which can be understood by the right personal. By only connecting sensors to machines

[52] Bauernhansl, T.; Hompel, M. t.; Vogel-Heuser, B. 2014, P. 548
[53] Laney, D. 06.02.2001, P. 1–4
[54] Dorschel, J. 2015, P. 8
[55] Dietrich, D.; Heller, B.; Yang, B. 2015, P. 33, 77
[56] Dorschel, J. 2015, P. 261
[57] Sendler, U. 2013, P. 47

and other devices the desired insights cannot be delivered in a way that help to make better decisions.[58]

Thinking that Big Data Analytics (BDA) is about visualizing information via dashboards and reports by transforming it is the wrong approach. The analysis of Big Data is all about extracting valuable insights from that data and as a result empowering decision makers to make decisions based on information driven by data and not because of their feelings and experience.[59]

Advanced analytics refers to the use and application of statistics, algorithms and other mathematical tools applied to business data in order to generate information and increase the value of the data collected by deriving the desired correlations. From the manufacturing point of view, operations managers use advanced analytics to analyze historical process data, identify patterns and relationships among different processes and their various input factors to realize optimizations.[60]

#### *2.7.1.1 Use cases and applications*

As shown in Figure 2-12 the biggest concern about implementing Big Data analytics is the requirement of a large investment. The two following biggest concerns detected in the survey conducted by Pearson, M. et al. 2014 are security and privacy issues. Due to the fact that the main competitive advantage of manufacturing companies is often the knowledge about specific processes the fear of this knowledge being revealed because of these security issues often exceeds the benefits accompanying the implementation of Big Data Analytics. This leads to a lack of applications in the manufacturing segment and therefore the current use cases are limited to applications with little risks although the possible applications are numerous.[61, 62, 63, 64]

[58] Lee, J. et al. 2013, P. 38
[59] Kaisler, S. et al. 2013, P. 997
[60] Auschitzky, E.; Hammer, M.; Rajagopaul, A. 2014, P. 1
[61] Li, J. et al. 2015
[62] Lee, J. et al. 2015
[63] Manyika, J. et al. 05/2011
[64] Schaeffer, C. 2013

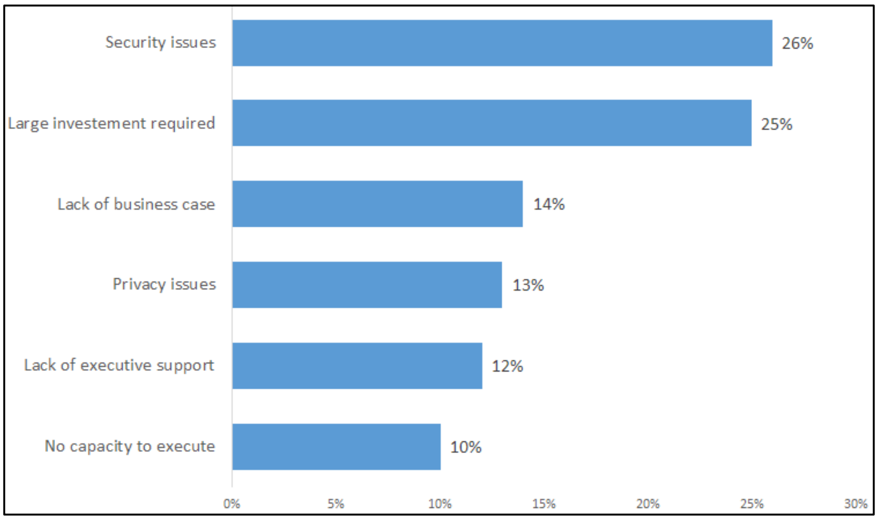



*Figure 2-12: Greatest concerns about the use of big data analytics[65]*

## Predictive and preventive measures

Modern manufacturing machines are already today collecting numerous data about performance, utilization, machine condition, environmental conditions and so on. With the right sensors and technology also a retrofitting of older machines can be done. By collecting the data over a longer period of time different types of predictions according to the defect behavior of critical parts can be made. Sneaking deviations of the predetermined target figures like increases in temperature or occurring unwanted vibrations can be determined early and maintenance tasks can be scheduled according to the remaining functional available hours of the, soon to be, defective part.[68]

By discovering the underlying patterns costly failures and unplanned downtimes of the machinery can be reduced to achieve greater asset sustainability and near zero breakdowns. By making those previous invisibilities visible the processes can become more stable, the achieved quality can be increased and the overall efficiency is increased.[69]

Spare parts can be organized in advance and thus downtimes lowered. To be able to make those predictions reliable the surveillance of only one machine may not be enough and therefore also the machine manufacturer should step in. With this additional service the manufacturer can add an extra business model of maintenance support activities where e.g. guarantees of a specific percentage of working hours for machines can be offered.[70]

Besides the predictive and preventive measures described above there are some other use cases but most of them are still under investigation and real world commercial implementations need to follow.

[65] Pearson, M. et al. 2014, P. 7
[68] Bauernhansl, T.; Hompel, M. t.; Vogel-Heuser, B. 2014, P. 545
[69] Lee, J. et al. 2015, P. 3
[70] Bauernhansl, T.; Hompel, M. t.; Vogel-Heuser, B. 2014, P. 545

### Research and development (R&D)

One advantage of Big Data in the R&D phase can be realized with an advanced PLM. The last decades IT support systems have been developed and so far have been very useful until now. The problem with these systems is that they are often kept in silos and therefore not connected to each other. The consistency of data and the according different data formats often lack a real industry standard and therefore can only be used limited. One benefit gained by including data from all different sources into one superordinate PLM system would be a reduction of development time because OEMs and other partners in the development process could work together. The findings about the previous product of all partners along the value generation chain can be included in the design phase for the next product. As it is well known 80% of the costs are determined in the design phase and savings in this phase are really paying off. A more intense collaboration with suppliers could also lead to improvements in the first time right approach and therefore result in a reduced need for (human) resources. The problem accompanying this application are once again the high investment costs of a new system with the appropriate features which would have to be deployed up- and downstream to benefit the most.[71]

### Supply chain

Big Data and Analytics can support forecasting the demand especially when adding data from external sources like promotion, launch and inventory data to reduce the gap between the supply and the actual demand. [72]

### Production

Besides the previous mentioned effectivity gains using predictive and preventive measures Big Data collected by the sensors installed at the shop floor can be used additionally to display the production process virtually in real time and help to increase efficiencies using simulations according to the real time data. The analysis of historical and real time production data can thus support the theory of a digital factory where the objective is to evaluate the optimal production system from layout to sequencing of steps for the specific products. Leading automobile manufacturers have already implemented parts of this technology and are currently using this method to optimize their production processes. [73]

### Business models

One essential element often mentioned in the context of I4.0 is the formation of new and data driven business models.

A digital business model arises if digital technologies trigger substantial changes the way a business is carried out and generates its revenues.[74]

[71] Manyika, J. et al. 05/2011, P. 77–81
[72] Manyika, J. et al. 05/2011, P. 77–81
[73] Manyika, J. et al. 05/2011, P. 77–81
[74] Veit, D. et al., P. 7

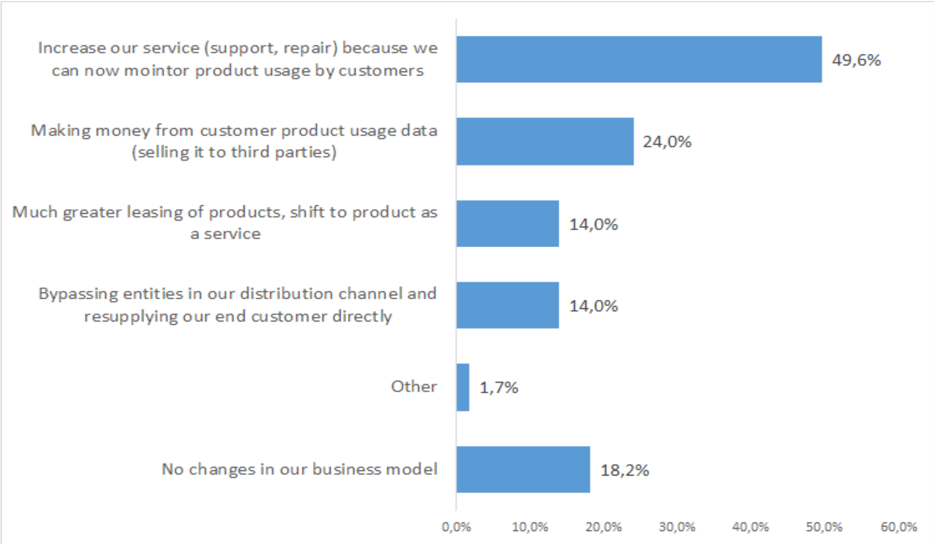



*Figure 2-13: Business Model Changes Made by Companies due to IoT Technologies*[76]

As it can be seen Figure 2-13 only 18,2% of the interviewed companies made no changes to their business model as a consequence of their I4.0 initiatives.[77]

Although it seems that there are numerous applications already installed no real public use cases are available. Often these initiatives are considered as competitive advantage and therefore are not published.

#### *2.7.1.2 Implementation Hurdles*

The biggest hurdles in implementing a Big Data and Analytics strategy are as already mentioned the costs arising with implementing a consistent data platform which is required for advanced analytics. Additional costs would come along with the development of interfaces and protocols to efficiently share the data between the different points and levels of origin and thus type and format enterprise wide and beyond. Furthermore, including all the partners of the production network needs commitment from all sides across the company boarders. To successfully lift the potential that is hidden in the vast amounts of data already available and continuously generated it is not enough to just provide a proper IT system. The leadership will have to establish a shift in the corporate culture to open todays data silos generated by the different departments. [78]

A study conducted by TATA Consultancy Services shows that among over 400 global companies only 4% percent agreed that they had the right people, right intents and appropriate tools for big data to obtain meaningful insights from the data and act on it accordingly.[79]

[76] TCS 2015, P. 14
[77] TCS 2015, P. 14
[78] Manyika, J. et al. 05/2011, P. 83
[79] Bi, Z.; Cochran, D. 2014

### 2.7.2 The Cloud

The cloud, also often referred to as cloud computing in the context of I4.0, is the on demand delivery of computing resources over the internet.[80]

The term cloud should indicate that the services of a provider can be accessed via the internet. Those resources are in general virtual which means that the user always has a customized view onto this infrastructure without any restriction for the applications. Additionally, cloud services are almost always scalable. So when an application requires more resources these can be provided instantly and with no effort. The need to invest in hardware is reduced and the available capacities are enormous.[81]

The National Institute of Standards and Technology (NIST) identified five essential characteristics when defining the term cloud computing:[82]

#### On demand self-service

The user himself can provision the required capabilities like network storage and server time as needed automatically and without the need of interaction of any personal by the service provider.

#### Broad network access

The capabilities provided can be accessed with any device such as smartphones, tablets, workstations or laptops with standard clients.

#### Resource pooling

The resources like storage space and processing power of the provider are assigned according to the customer's needs. The resources are location independent so the user has only limited knowledge and control of the actual location of the resources.

#### Rapid elasticity

The capabilities provided can automatically be up- and downscaled according to the needs of the user. It appears that the resources provided are unlimited and can be appropriated in any quantity at any time.

#### Measured service

The cloud automatically controls and optimizes the resources by measuring the types of services used in a, to some extent, abstracted way. To support full transparency, the usage can be monitored, controlled and reported by the provider as well as by the user.

#### *2.7.2.1 Use cases and applications*

The NIST - report also identified the main applications. Those are often summarized with the expression Xaas which means **X** (which is used as a variable that can be replaced by

[80] *IBM Corporation 2016*
[81] Baun, C. et al. 2011, P. 2
[82] Mell, P. M.; Grance, T. 2011, P. 2

specific terms) **a**s **a S**ervice. XaaS should represent the different use cases which can be applied when using cloud computing. The NIST report characterized the three different types of XaaS which are explained briefly in the following.

### Infrastructure as a service

Infrastructure as a service (IaaS) provides the user with an abstract view of virtual hardware like storage systems, networks or workstations. In the user interface a set of resources are displayed and the user can then allocate those to his specific needs. A well-known example is the service provided by Dropbox or Microsofts' OneDrive where the user is able to upload, manage and work on files via the internet.[83]

### Platform as a service

Platform as a service (PaaS) is a model typically provided for the IT department of a company or any other program development institution. The PaaS provider hosts nearly the entire hardware and software on his infrastructure. The applications are developed by the IT departments and can afterwards be accesses by the users e.g. via the web browser. The biggest advantage of the PaaS service is that the maintenance and service of the hardware components is ceded to the provider.[84]

### Software as a service

Software as a Service (SaaS) is a model in which software is distributed by a provider and made available for its customers through a network, typically the internet.[85]

The applications are running in the provider's cloud infrastructure and are accessible through clients like a web browser or a program interface.[86]

For the user it is not necessary to install the application local and the necessary resources can be provided.[87]

### Connecting work preparation and manufacturing

In a paper published by Brecher, Lohse, Königs 2015, the results of a research project about implementing the cloud into the manufacturing environment of ten small and medium sized companies were presented. The processes of these companies between the stations were identified starting from the order intake and followed down to the final quality control. The goal was to determine and optimize the efficiency of the CAD-CAM-NC procedure chain as well as the flow information at the specific stations. The result was a generic reference process which could be applied to most of the small and medium sized

[83] Baun, C. et al. 2011, P. 31
[84] *Rouse, M. 2015*
[85] *Rouse, M. 2010*
[86] Mell, P. M.; Grance, T. 2011, P. 3
[87] Baun, C. et al. 2011, P. 37

companies in this field. This process was enriched with the flow of information to and from a centralized database (DB), in the form of a cloud, and is shown in Figure 2-14.

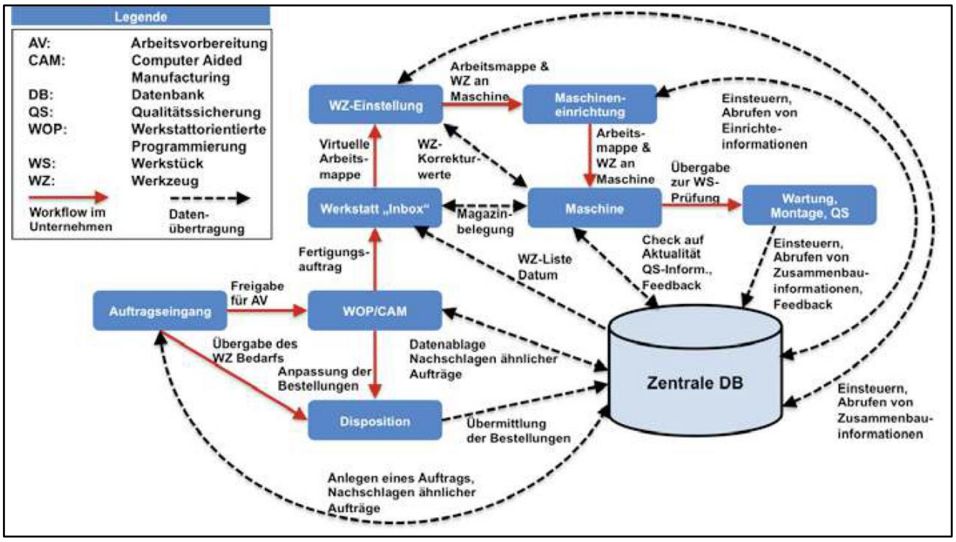



*Figure 2-14 Reference process of work- and information flow*[88]

The process presents the possible points of an interaction with the database starting with the order intake. In this phase the order is transferred to the DB and immediately previous orders are checked for similarities that could be reused in the current process. The next step is that the work preparation starts to check for similar NC programs of previous jobs and tries to find the one with the lowest need for modification to fulfil the current specifications. After finishing the planning tasks, the order is then sent to the shop-floor-inbox which is also connected to the DB and requires the needed machine settings and occupancies to sequence the orders in consideration of the set up times and due dates of the products to be made. After the sequence is determined the order is passed onto the tool settings and the machine set up which are both supported by the DB holding information about the tool assembly, compensation values of the tools, the clamping situation and other necessary data. The next phase is the processing on the machine which can be supported by the DB checking for the validity of the NC program. In the last step the documentation of problems and changes occurring during the processing is created and updated in the DB, the assembly information is demanded and the quality control parameters are requested. After all processes have been finished the documentation is stored in the DB.[89]

The main advantage of this concept is to have one centralized data container which can be accessed by many different decentralized clients and in which all the gathered information is stored following the single source of truth principle. This research field is still under

[88] Brecher, C.; Lohse, W.; Königs, M. 2015, P. 15
[89] Brecher, C.; Lohse, W.; Königs, M. 2015, P. 2–3

investigation but great benefits can be expected in terms of time and effort savings when the concept is matured. [90]

### Cloud ERP system

Conventional ERP systems installed locally on the IT infrastructure of a company usually require a high initial investment and the ongoing costs to manage the hardware, software and the facilities to run these systems are also very high. The advantages previously mentioned like scalability and the user demand specific capabilities of a cloud are the ideal characteristics when installing or reintroducing a new ERP system because the initial as well as the ongoing costs can be decreased to a sufficient amount needed at that specific time. The fact that cloud software is from the ground up designed for maximum network performance enables such systems to provide an up to 99,98% availability which often cannot be achieved with on premise installed systems. An additional advantage of cloud ERP systems is the fast deployment rate because no additional hardware is required and therefore can be rolled out easily to all the divisions and subsidiaries around the globe.[91],[92]

As it is shown in Figure 2-15 the share of installed cloud ERP systems compared to on premise systems reached 11% in the investigated period from 2014 to 2015 (02/2014 – 02/2015) as the ERP report by Panorama Consulting Solutions shows. This value increased in the following period up to 27% which can be explained by the increasing number of vendors offering such systems.[93]

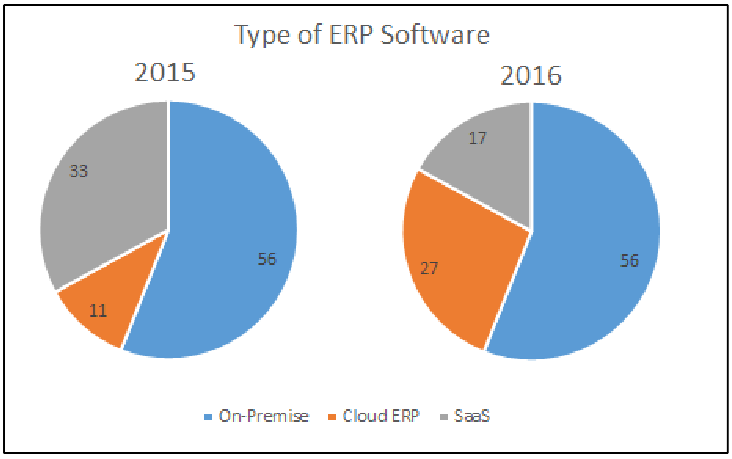



*Figure 2-15: Type of installed ERP systems in 2015 / 2016 [94,95]*

#### *2.7.2.2 Implementation Hurdles*

The security of sensitive data in the cloud is the biggest problem for implementing cloud computing in companies although cloud providers are constantly improving their security

[90] Brecher, C.; Lohse, W.; Königs, M. 2015, P. 2–3
[91] *Netsuite 2016*
[92] Raihana, G. F. H. 2012, P. 78
[93] Panorama Consulting Solutions 2016, P. 12
[94] Panorama Consulting Solutions 2015, P. 7
[95] Panorama Consulting Solutions 2016, P. 12

practices and features, but the market is still immature. Thus still most organizations continue to operate their own internal IT services.[96]

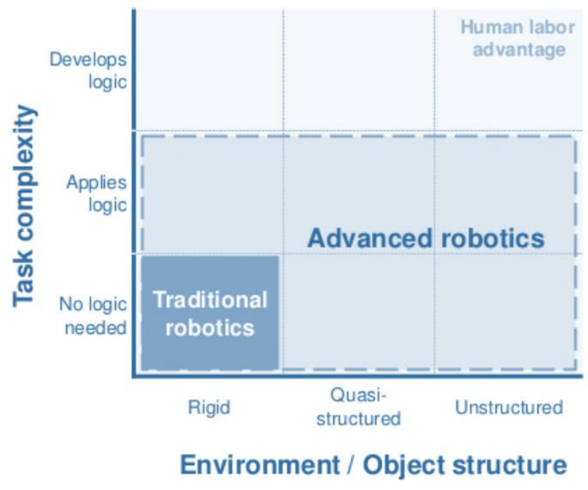
Another big problem, especially for small and medium sized companies, which are often located on the countryside is to have sufficient bandwidth to be able to achieve the desired and necessary transfer speeds. This issue is often depending on the surrounding infrastructure of the company's location and might be one reason for limited availability.[97]

The risk of data loss is a third problem that has to be considered. If sensitive information is viewed, stolen or used by an unauthorized individual due to an attack or human error, application vulnerabilities or poor security practices, the whole business of the company could be in danger.[98]

### 2.7.3 Advanced robots

The intense use of robots is often by mistake implying a factory without any workers. But in the context of I4.0 the use of robots is more directed towards a co-working environment between human and machines. With this research field the trend regarding the demographic change mentioned in section 2.3.2.7 should be met.

As it can be seen in Figure 2-16 there will always be an area where the human is to put in favour against any robot. Highly complex tasks where new logic needs to be developed (including creative thinking and involves problem solving) will always remain as tasks to be best performed by humans.




- Rigid: environment and objects are in predicable position or move at known speeds
- Quasi structured: Environment or objects have some degree of variability and localization of object requires additional sensing
- Unstructured: Environment and objects have no predetermined orientation and/or structure and the localization requires additional sensing

*Figure 2-16 The scope of advanced robots[99]*

[96] *Howard, C. et al. 2012*
[97] Kagermann, H.; Wahlster, W.; Helbig, J. 2013, P. 26
[98] Brook, J. M. et al. 2016, P. 8
[99] The Boston Consulting Group 2016, P. 6

Humans are and will be an integral and crucial part of the production environment today and in the future. They are the most flexible and the most intelligent element of the factory but in the context of I4.0 the collaboration between humans and robots' will be closer than ever before.[100]

#### *2.7.3.1 Use cases and applications*

Figure 2-17 shows the main application area for industrial robots today is in the automotive industry. This sector is especially known for its high degree of automatization and therefore it is obvious that the number of robots per employee is seven times (Japan and Germany) to 14 times (USA) higher than in the other general industry. The automotive industry is also known for the high production volume which justifies or even calls for the excessive use of industrial robots. But the trend to an increasing number of variants with a high level of customization is increasing and therefore a higher degree of flexibility in the production line is required.

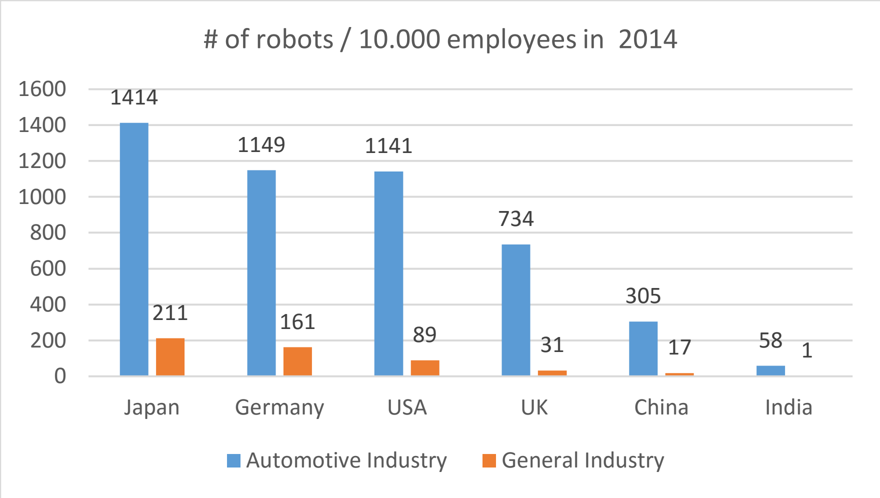



*Figure 2-17 Robots in automotive / general industry in 2014*[101]

Audi and BMW for example increased their range of models every two years per one new model and Mercedes released two new models every three years when looking at the time between 1990 and 2010.[102]

Conventional industrial robots like those mainly used in the automotive industry have several aspects that makes it simply impossible to co-work with them. Typically, they weigh around one ton and the tools they are operating and dealing with are heavy as 150 kg in case of a spot welding gun. These two factors and the resulting inertia in combination with a working speed of 2m/s would lead to serious or fatal injuries if a collision with a human

[100] Botthof, A.; Hartmann, E. A. 2015, P. 49
[101] Statista 2015, P. 18
[102] Schulz, M.; Göpfert, I. 2013, P. 238

occurs and therefore those robots need to be located in isolated areas to avoid any unwanted contact with the personal.[103]

*Figure 2-18 Iiwa by KuKa[104]*

So if the intended collaboration should really be established the co-working robots have to have sensors, motors, damping and other systems that are capable to create a safe environment for humans working next to such a robot. One example for robots following these restrictions is the one arm, seven axis robot Iiwa (which stands for intelligent industrial work assistant) developed by Kuka displayed in Figure 2-18. It is already in use at the Czech Skoda plant where it is supporting the assembly line for the gearbox.

Another example is the UR series developed by Universal Robots which is currently in use at the assembly line co-working with humans in the BMW plant in Spartanburg, US, where it is fixating the interior of a door as it can be seen in

Figure 2-19. In this case the robot is directly working side by side with the human worker and takes over the non-ergonomic and exhausting task of applying constant pressure while applying the door sealing.[105]

*Figure 2-19 Co-working robot at line at BMW plant[106]*

A so called sensitive robot can be used without a cage and workers can constantly work in close proximity to them. When compared to conventional robots which are locked in cages

[103] Botthof, A.; Hartmann, E. A. 2015, P. 61
[104] KuKa AG
[105] Pielot, M.; Diefenbach, S.; Henze, N. 2015, P. 372
[106] www.mittelbayerische.de

the worker and the advanced robot can share the same working environment and entering the robots' area of motion is going to be the standard and not the exception. With the increasing use of additional sensors, a collision with the robot will not lead to any injuries or harm the worker next to the robot.[107]

Additional to the ability to co-work along with humans the new generation of robots is lightweight and therefore can also be mounted onto automated guided vehicles (AGVs) which makes them mobile and ready to use at multiple locations fulfilling multiple tasks.[108]

Another application for the human robot collaboration is the assistance of robots for workers with monotonous and physically exhausting tasks. The intense use of robots in the automotive industry explains that the implementation of this use case is also mainly performed in this industry sector. Figure 2-20 shows a robot assisting the worker in terms of providing parts that are stored and located in large boxes. Previously the worker had to bend over and reach for the part. Now the robot moves into the box, grabs one of the parts and hands it over to the worker. The non-ergonomic movement of bending over is in this case performed by the robot and this results in a much healthier and more ergonomic working environment for the worker.[109]

*Figure 2-20 Assistance robot at Audi[110]*

The applications where robots can be used have evolved over time. Previously robots where solely used for repetitive tasks that require speed, strength and only moderate precision. Most of these activities were material handling, processing, welding and soldering as well as assembly activities.[111]

#### *2.7.3.2 Implementation Hurdles*

Due to the fact that robots still can perform only those tasks they have been programmed for, medium and large scale production and the repetitive work there will stay the most attractive field of application. Although the costs for those robots are declining many tasks are too complex to be automated. The rate of adoption will be determined by the ratio

[107] Botthof, A.; Hartmann, E. A. 2015, P. 62
[108] Pfeiffer, K. 2016, P. 2
[109] Feigl, K. 12.02.2015, P. 1–2
[110] Audi AG 12.02.2015
[111] Sander, A.; Wolfgang, M. 2014, P. 2

between wage rates and flexibility in labour and some industries will very unlikely benefit from robots as it can be seen in Figure 2-21.[112]

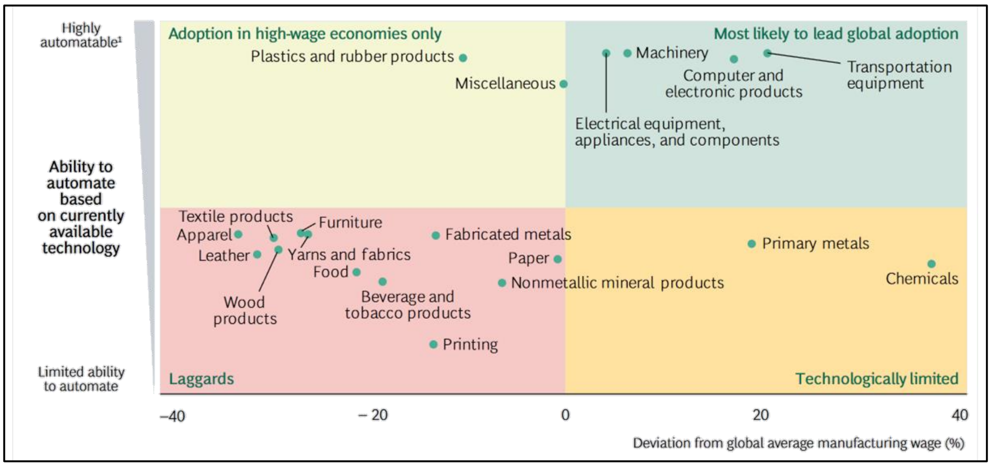



*Figure 2-21: Industries likely to benefit from robots[113]*

Process reliability is also a crucial factory in industrial manufacturing because it strongly influences the production volume. The requirements for safety in human robot collaborating environments often leads to frequent stops of the production line which is negatively influencing the output. This is one reason for the still limited distribution of advanced robots. Today's research focuses on the alternative scenarios to the total stop of the robots' motion. One solutions could be to implement different threat levels where the speed of the robot is reduced according to the current threat level. When the threat is remedied the robot would automatically continue the operation with the predetermined parameters which would lead to a higher overall process reliability.[114]

Another challenge especially for small and medium enterprises is the detailed risk analysis when introducing a robot into the production. Because the robot itself has no clearly defined application a CE certification is not possible and therefore a detailed analysis of the robot when it is assembled as it is used in the collaborating environment has to be done which takes a lot of time and is an additional cost factor.[115]

### 2.7.4 Industrial Internet of Things

In this chapter the term Industrial Internet of Things (IIoT) is used to subsume all the technologies that enable interactions of physical objects with the internet or other networks in the manufacturing industry. To enable any kind of IoT the objects which should be connected to the internet have to be clearly addressable and therefore the change from IPv4 to IPv6 was inevitable.

[112] Sirkin, H. L.; Zinser, M.; Rose, J. 2015, P. 13
[113] Sirkin, H. L.; Zinser, M.; Rose, J. 2015, P. 13
[114] Heß, P.; Wagner, M. 2015, P. 11
[115] Bauer, W.; Bender, M.; Rally, P. 2016, P. 102

### *2.7.4.1 IPv4 vs. IPv6*

The importance of a unique identity of an object and its application has already been mentioned in chapter 2.6.3. To be able to address a certain object via the internet it has to have a unique attribute for its individual identification. This attribute is the so called internet protocol (IP) address which was previously deployed using version 4 (IPv4) providing approximately $2^{32}$ unique addresses. Due to the fact of the vast expansion of web-enabled devices these were not sufficient anymore and a new standard (IPv6) providing $2^{128}$ addresses have been established which was required to enable an IoT with its estimated 50 billion connected entities in 2020.[116,117]

### *2.7.4.2 Sensors, Actuators & Microprocessors*

The required addresses to identify the object have been established introducing IPv6. The next step towards introducing an IIoT is to add some form of intelligence to the different objects. This intelligence can be realized by sensing the objects current status and environment followed by a subsequent processing of the available information and finally sending the results either to the actuator changing the current status of the object or transmitting its results to other objects. By adding microprocessors or any other logic to the objects they are transformed into so called smart objects enabling them to perform tasks that were previously unfeasible.[118]

The capability of sending as well as receiving information is covered in more detail in the next subchapter.

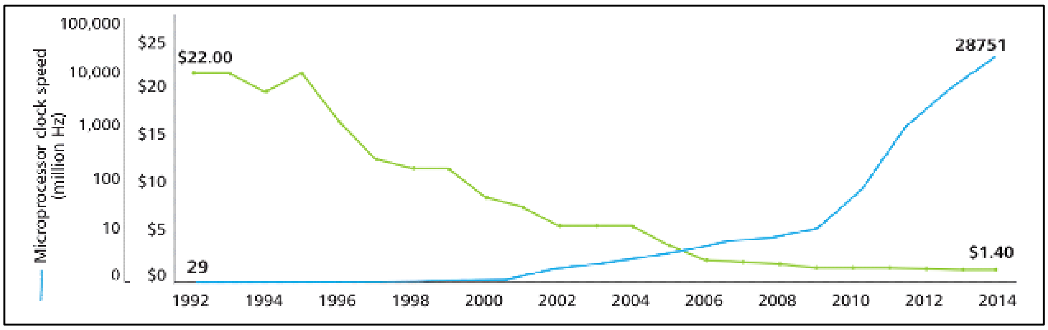



*Figure 2-22 Development of sensor prices and computing speed[119]*

The development of the prices for sensors in correlation with the maximum processing speed of the microprocessors as shown in Figure 2-22 were two crucial factors for the vast distributed deployment of fast, small and cheap sensors and can be mentioned as additional enablers for the IIoT. [120]

[116] Holdowsky, J. et al. 2015, P. 10
[117] Graziani, R. 2012, P. 7
[118] Al-Fuqaha, A. et al. 2015, P. 2350
[119] Holdowsky, J. et al. 2015, P. 8
[120] Holdowsky, J. et al. 2015, P. 8

So far the object can be addressed with a unique name (IPv6) and has the capability of gathering and processing information. This is realized by adding sensors and microprocessors. To change the current status of the object the communication to the actuators needs to be established. Therefore, the next step is to link the internet address to the physical object. In the context of I4.0 RFID is the dominant technology suggested to use when automated identification technologies are discussed.

#### 2.7.4.3 RFID

The Radio Frequency Identification tag (RFID) is like the barcode a member of the group of automated identification systems and can be seen as a cross sectional technology which can be used in many different applications.[121]

Every RFID System exists of 3 parts. These are the RFID transponder, the RFID Reader and the information system which reads from and writes to the transponders and is processing the data.[122]

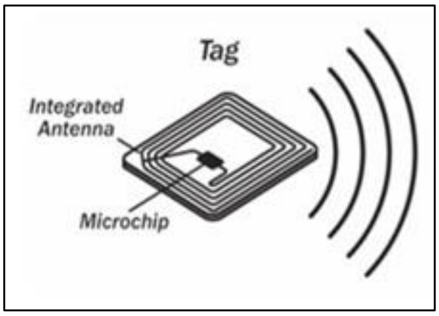



*Figure 2-23Passive RFID tag[123]*

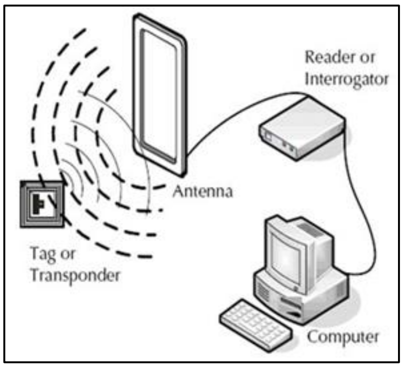



*Figure 2-24 RFID system[124]*

A passive RFID transponder exists of a microchip and an antenna. Is the RFID transponder within a specific range of the sending field of a reader the transponder is activated by transmitting the necessary energy, data and tact. The transponder answers to the reader signal by sending his response data which is then processed by the information system for further use.[125]

The main advantages of RFID compared to the conventional 2D barcode or any other automated identification technology is the combination of the following capabilities. Readable without direct visual contact, the capability of reading numerous different RFID transponders in the reading field simultaneously and the higher storage capacity so more information can be stored on each tag. [126]

[121] Tamm, G.; Tribowski, C. 2010, P. 9
[122] Tamm, G.; Tribowski, C. 2010, P. 13
[123] *www.barcodesinc.com*
[124] *www.barcodesinc.com*
[125] Tamm, G.; Tribowski, C. 2010, P. 14
[126] Tamm, G.; Tribowski, C. 2010, P. 3

One reason for the ongoing distribution of RFID tags and its applications is the reduction of the costs for the individual tags. In the graph all tags types and the different frequencies used have been considered.

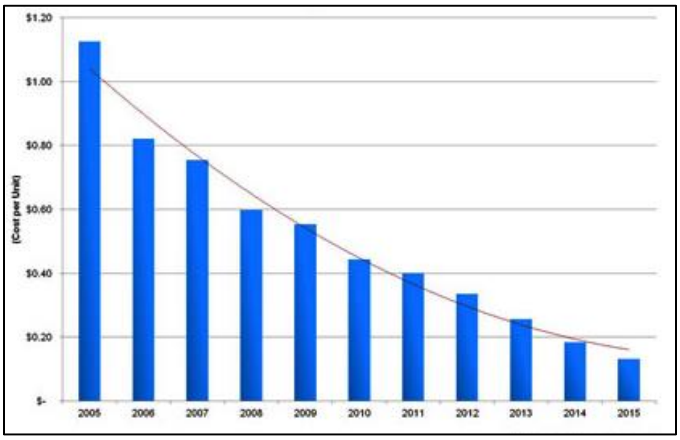



*Figure 2-25 Global Average Factory Selling Price of RFID transponders (extrapolated to 2015)*[127]

### *2.7.4.4 Use cases and applications*

In the context of I4.0 the technology is mainly used for the identification of the objects and the most prominent application is the tracking and tracing of the objects along the supply chain as mentioned in the last example of this chapter. The more sophisticated use case of the multi product line was chosen because it additionally implies the Bluetooth technology and shows how the concept of batch size one can be realized in practice using RFID technology for the individual identification of a product. The example of the smart tools shows how the RFID technology can also be used for the optimization of the manufacturing process. In this case the RFID tag is located on the tool and not as usually expected on the product.

#### Multi product line

Bosch Rexroth, a manufacturer for electric devices and controls started the production at a new assembly line equipped with RFID and Bluetooth technology to connect the individual worker to the specific station he is currently working at. When the person is in close proximity to one specific station it is recognized via Bluetooth identifying the worker. The according information required for the current task can be displayed at the monitors and is tailored to the specific person currently working at this station. The instructions of how the assembly process has to be carried out can be displayed according to the product that needs to be assembled and which is identified via the RFID tag placed on its mounting device. Those instructions are also tailored to the person performing the job according to the knowledge, language and experience of the specific worker. The system also tracks the individual parts used for each assembly and has the possibility to automatically trigger the reordering of the used parts if they reach a critical level of inventory. By applying these

[127] *Sower, V. et al. 2012*

technologies which are enabling individualized instructions according to the current job they managed to merge the previously needed three assembly lines into one. On this single line now 200 different types of valves can be assembled by any worker even without preceding training. The installed system now additionally prevents errors due to the appropriate provision of information and additionally enables a reduction of inventory due to the tracking of the actual parts that have been used and the installed capability of automatically reordering those parts when they are needed.[128]

#### Smart Tools

In the context of I4.0 the tool management can be optimized using RFID technology. A tracking and tracing system can be used to identify the tools location in real time and additional information like wear can also be provided. Using RFID enables the creation of a so called digital twin of the tool. The necessary machine parameters for the specific tool as well as the data gathered during the measurement of the tool can be directly stored on each individual tool. This could help to decrease set up time and reduce errors due to human failures. This is becoming more important in respect to the increasing individualization of the products and the trend towards batch size one and the resulting need for permanent tool changes.[129]

#### Supply Chain Management

The SCM is focusing on the material and information flows inside a company and along the value generation chain across the company boarders including the suppliers and other partners up- and downstream. RFID in this context can support the event based management of the supply chain. Logistical information as well as part related information can be provided in real time. If process critical events occur the partners downstream can be informed immediately and can take the appropriate actions to keep the production running e.g. shifting the production sequence according to the current events.[130]

### *2.7.4.5 Implementation Hurdles*

Due to the fact that RFID technology is still very expensive although the costs for the individual transponders declines as seen in Figure 2-25, the costs to implement and the ongoing costs for the transponders are still too high so the potential savings for companies as well as the ROI are not very attractive.[131]

EPCglobal, the standardization body for the RFID industry set the target costs for an RFID tag to 5 € cents for a widespread implementation and a cost efficient tracking and tracing

[128] Swedberg, C. 26.08.2015, P. 1–5
[129] Abele, E.; Grosch, T.; Schaupp, E. 2016, P. 106–110
[130] Reinhart, G.; Engelhardt, P.; Genc, E. 2013, P. 104–108
[131] Scholz-Reiter, B. et al. 2006, P. 2

also of low value inventory which means the current costs of 10-15 € cents are still too high.[132]

The costs are still the main reason why RFID is still not adopted in a broad sense although the possible advantages could be enormous.

Another challenge is the integration of the data generated by the RFID tags and readers into the currently deployed enterprise resource planning (ERP) system, MES or any other industrial software which makes it still difficult to get the best use out of it.[133]

### 2.7.5 Additive manufacturing

Additive manufacturing (AM) or 3D printing are the two most frequently used terms describing different types of generative manufacturing methods. Other terms often used synonymously are rapid prototyping, desktop manufacturing, freeform fabrication or direct digital manufacturing.[134]

AM is a manufacturing technology that creates products by adding one layer of material to the next instead of segregating material from a solid. As you can see in Table 2-1 there are several different methods of how the layers are created and merged. In the right column of this table you can see the different materials which can be used in the AM process representing the wide scope of AM today.

#### *2.7.5.1 The process*

Additive manufacturing is an automated and layer repeating process based on the layer technology. The process starts with a virtual three dimensional CAD model representing the part. The set of data is either generated with a 3D CAD design tool, scanned or determined via a computer tomography. The first step is to separate the model into layers using special software. The result is a set of contoured virtual layers all with the same thickness. The data sets of the layers exist of contour information (x, y), layer thickness (dz) and the layer number (z) and is transferred to the machine. The machine then operates in two process steps. The first step is to generate the desired layer according to the contour using one specific type of technology (see Table 2-1). The second step is to lower the platform the previous layer was built on according to the layer thickness. Repeating the first step connects the currently generated layer to the previous one and by continuing this process the part can be created starting from the bottom and finishing it by going layer after layer to the top.[135]

[132] Manyika, J. et al. 2015, P. 102
[133] Sheng, Q. Z.; Li, X.; Zeadally, S. 2008, P. 23
[134] Schmid, M. 2015, P. 3
[135] Gebhardt, A. 2014, P. 4–5

*Table 2-1 Overview of additive processes*[136]

| Type | Abbreviation | Description | Material |
|---|---|---|---|
| Fused deposition modelling | FDM | Plastic filaments are led through a heated nozzle and adhere in the hot state | Amorphous thermoplastics |
| Poly jet modelling | PJM | Melted wax is led through a printer head (like ink jet printing) and the drops cool when dropped | Waxes |
| Multi jet printing | MJP | Small droplets of UV hardening polymers are deposited in a liquid state and are cured using a UV source | UV sensitive acryl Epoxies |
| Stereolithography | SL(A) | An UV laser writes the layer information into a bath of UV curing polymers | UV sensitive acryl Epoxies |
| 3D Printing | 3D-P | The powder particles of the substrate are bonded using a printer head applying a suitable binder | Powdery plastics, metals, ceramics |
| Selective Laser Sintering | SLS | The spatial introduction of the energy provided by a laser fuses the powder particles | Semi crystalline thermoplastics |
| Selective Laser Melting | SLM | The spatial introduction of the energy provided by a laser fuses the powder particles | Metal powder |
| Electron Beam Melting | EBM | The energy introduced by an electron beam melts (welds) the powder particles | Metal powder (mainly Titanium) |
| Direct Metal Deposition | DMD | A fine metal powder jet is sprayed into the focus of a laser and spatially resolved and thus welded | Weld able metal powder |

Figure 2-26 shows exemplary the schematic process of Selective Laser Melting - SLM respectively Selective Laser Sintering - SLS. The procedure works as follows starting at the top left picture: [137]

1. Fusing and solidification of the powder according the desired contour in one process step
2. Lowering the building platform and simultaneously rising the powder bed
3. Recoating – transferring the powder onto the building platform e.g. with a roller

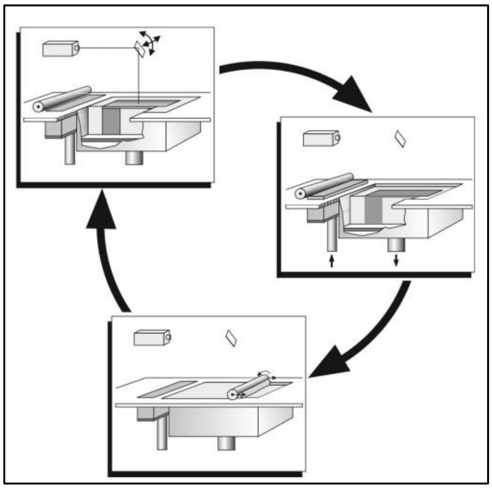


*Figure 2-26: Schematic AM process*[138]

[136] Schmid, M. 2015, P. 4
[137] Gebhardt, A. 2014, P. 44
[138] Gebhardt, A. 2014, P. 44

After the last step is completed the process starts over again until the desired part is finished. In the end the remaining powder is removed and the part can be cleaned and then used or further processed.

#### *2.7.5.2 Drivers*

The use of AM in production instead of using conventional methods can be justified by the following drivers: [139]

##### Product

The complexity of the product is so high that the use of conventional production methods would lead to tremendous costs due to their limited capabilities.

In combination with small series production or batch size one the costs of producing tools to manufacture the parts e.g. moulds would exceed the justifiable price. Another aspect could be that the volume of material which has to be removed or the time to remove the material is not reasonable.

Another factor considering the product and its respective complexity is that AM would be the only technology that makes the production of the product feasible.

##### Process

In terms of the process a reduced manufacturing complexity can be achieved using AM. A part that can be produced in a single step in AM might need to be processed on several machines to generate the desired geometry.

Due to the fact that sometimes the manufacturing of the tools takes a significant amount of time the relatively slow material deposition rates of AM machines are still sufficient enough to produce the parts faster than the other way round.

The logistical aspect due to the possibility of decentralized production using AM can justify the production of parts that could otherwise be manufactured more efficiently. This is especially interesting when thinking of spare parts that could be produced on site.

##### Lifespan

The achievable properties using AM e.g. in terms of flow of forces or reduced weight can lead to lower overall costs in respect of the whole life span of the product. This could also justify the use of AM machines.

#### *2.7.5.3 Use cases and applications*

The main industrial applications for additive manufacturing according to the VDI status report are: [140]

[139] Fraunhofer IPT / ITL; KEX AG 23.02.2016, P. 10
[140] Ensthaler, J. et al. September 2014, P. 6–7

- manufacturing of small series and / or
- customer specific products
- manufacturing on demand
- manufacturing on site
- manufacturing of spare parts for older serial produced products and
- the shortening of the product development process iteration intervals as well as the
- lightweight construction.

### Aviation Industry

The aviation industry is one of the most ambitious industries in advancing the AM technology due to the fact that weight in general plays a crucial role in this industry sector. Cost effective operation is the overall goal and therefore it is the leading industry in additively manufacturing metal and plastic parts to reduce weight and therefore costs. Another aspect that makes the aviation industry a perfect match for AM are the volumes of the parts that need to be produced not exceeding the cost effective level which AM can provide.[141]

Traditionally the spare parts demand for aircrafts is hard to calculate. E.g. most spare parts for the Airbus fleet are requested rarely or very rarely. In this context, parts that are ordered on average five times in two years are considered as *high runners*. Airbus has to keep every component in stock or being able to produce it on short notice as long as at least five aircrafts of a specific type remain in service. For the A300/310 which ceased production in 2007 this means Airbus has to keep about 3.5 million spare parts which are occupying a gigantic amount of storage space and binds significant capital. In this case an advanced level of AM through which it is feasible to produce those spare parts when needed could significantly reduce both, lead time for those parts as well as inventories.[142]

The weight reduction which can reach levels of up to 75% would lead to a reduced fuel consumption of 6,4%. This scenario could be reached if the AM components, identified in the study conducted by Huang et.al. 2015 as replaceable by AM parts, are used to their full potential.[143]

In April 2015 the first 3D printed part was certified by the U.S. Federal Aviation Association (FAA) to fly inside General Electrics (GE) commercial jet engines. The part is the housing for a temperature sensor located in the inlet to the high pressure compressor at the turbine and the sensor provides data of pressure and temperature measurements for the engines' control system and is shown in Figure 2-27.

[141] Bouras, A. et al. 2016, P. 75
[142] *Anastassacos, T. 2015*
[143] Huang, R. et al. 24.04.2015

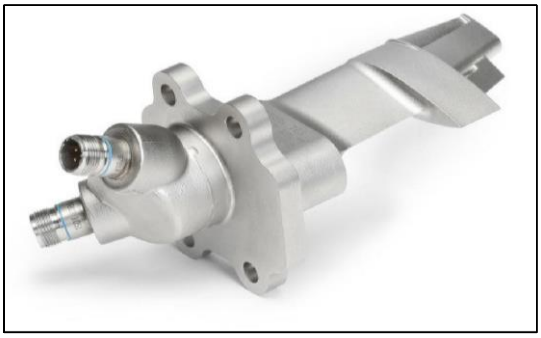


*Figure 2-27: Temperature sensor housing*[144]

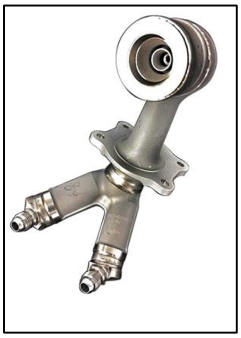


*Figure 2-28 Fuel nozzle*[145]

Another part developed by GE using AM is the fuel nozzle as it can be seen in Figure 2-28. The new type of nozzle is now five times more durable than the conventionally produced part, weighs approximately 75% less and it is designed as one part instead of previously 20 individual parts reducing the number of brazes and welds needed before.[146]

### Automotive Industry

The automotive industry is another industry segment, that benefits a lot from the advancements made in AM technologies. The two main factors for implementing this technology are to reduce the product development costs and the time to market. E.g. General Motors (GM) had already 18 machines in 2011 in their rapid prototyping laboratory which was able to produce about 20,000 parts per year and were responsible for the whole enterprises rapid prototyping tasks. GM uses the technology in many departments and throughout the whole development process. Designer and engineers are empowered to review and evaluate changes on the "real" part not having to wait for the prototype to be manufactured conventionally. This also eliminates the necessity of tooling in this section of the process enabling more frequent and cheaper iteration processes to determine the best modification of the part. Besides prototyping AM is also used for the aerodynamic testing of models and full sized vehicles. But the applications are not limited to models of the whole car, e.g. the air flow in the engine bay is also tested using models of engines, drive shafts, transmission and brake lines.[147]

### Jigs and Fixtures

Another application of AM is the production of jigs and fixtures. The reduction of fabrication expenses can reach from 50% to 90% if the usually conventionally manufactured elements are produced using AM. The even bigger benefit using AM in this area is that fixtures enabling only little time savings are also produced because of the reduced costs making them using AM. These fixtures would not be manufactured conventionally due to the higher costs and the resulting questionable ROI. AM enables

*[144] Kellner, T. 2015*
*[145] c.f. Kellner, T. 2015*
*[146] Kellner, T. 2014*
*[147] Fish, E. 2011*

higher accessibility of jigs and fixtures which result in a reduction of non-value-adding time required for placing and adjusting leading to an overall higher efficiency.[148]

*Figure 2-29 AM manufactured pallet for the production[149]*

The application of AM in this field is not only limited to jigs and fixtures. As shown in a use case by Stratasys 2013, a AM model of the finished part is used to pre-program the coordinate measurement machine taking this process off the critical path in the product development schedule.[150]

### *2.7.5.4 Implementation hurdles*

A study commissioned by the VDW (Verein Deutscher Werkzeugmaschinenfabriken) and conducted by the Fraunhofer Institutes of production technology (IPT) and transportation logistics (ITL) as well as the Knowledge Exchange AG (KEX AG) investigated the potentials and risks involving AM. Figure 2-30 shows the areas of the beneficial use of AM in respect to conventional manufacturing. As the figure shows the main benefits of AM are at manufacturing complex, individualized and small parts as well as the low volume production. In comparison with conventional manufacturing methods the cost advantages in the context of medium and large size production volumes of conventional techniques can only be compensated by AM when adding specific value. These values are the already mentioned complexity of the product, the complexity of the products and the advanced properties that can be achieved using AM.[151]

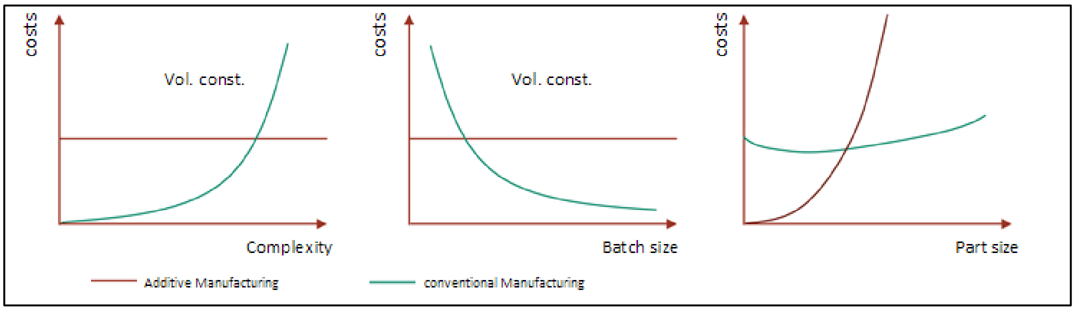



*Figure 2-30 Paradigms of AM[152]*

[148] *Stratasys 2014*
[149] *Stratasys 2013*
[150] Stratasys 2013
[151] Fraunhofer IPT / ITL; KEX AG 23.02.2016, P. 10
[152] cf. Fraunhofer IPT / ITL; KEX AG 23.02.2016, P. 9

The costs for achieving economies of scale via batch fabrication using AM are typically significantly higher than via injection molding techniques when producing standardized geometries.[153]

For mass production the biggest hurdle of AM is the cost of the material. For example, the most common AM material ABS can cost up to $80 US per kg as bespoke powder or filament. But when used for plastic injection molding a kilogram of ABS costs about $2.[154]

There is an interdependency within the layer resolution (layer thickness) and the overall scale of the produced parts. A thinner layer produces of course a better surface finish but also increase the total build time as more layers need to be created to generate the desired geometry.[155]

Another factor negatively influencing the widely distribution of AM as a manufacturing technology is the slow processing speed of the technology leading to high costs for the parts manufactured using AM.[156]

### 2.7.6 Augmented reality

Today the terms augmented reality (AR) and virtual reality (VR) are often used wrongly as synonyms. But there is a difference and a third substantial element which is often forgotten, the mixed reality (MR) also exists. MR is representing the space between those former and well known two others. The Virtuality Continuum presented by Milgram and Kishino shown in Figure 2-31 visualizes the levels of the different types of realities and in the following section the differences between the levels of those realities will be explained.

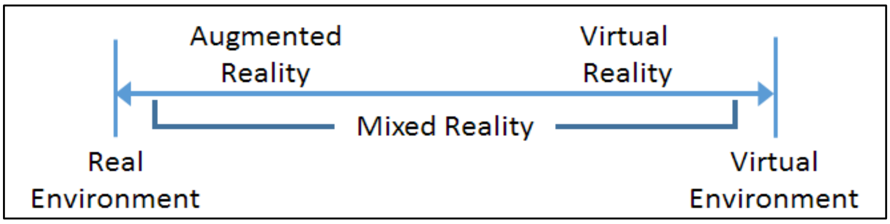



*Figure 2-31: Virtuality Continuum[157]*

On the left side the term real environment defines a world solely of real objects and includes also what is seen on a conventional screens showing real world scenes, e.g. a TV show. Where on the right side the term virtual environment represents a scene consisting only of virtual objects. Exemplarily a conventional computer graphic simulation as often seen in video games can be mentioned. As the figure forebodes a mixed reality is everything in between and represents a level where elements of both sides are merged. As an example

153 Gao, W. et al. 2015, P. 68
154 *Anastassacos, T. 2015*
155 Gao, W. et al. 2015, P. 68
156 Mellor, S.; Hao, L.; Zhang, D. 2014, P. 199
157 cf. Milgram, P.; Kishino, F., P. 3

for a mixed reality environment a display showing virtual objects embedded in a real world scene like the score and time inserted in a football broadcast can be mentioned.[158]

AR is designed to simplify the user's life by adding digital information into his immediate surroundings. VR located more on the right side of the figure completely immerses users in a synthetic world without seeing the real world. [159]

At this point it should be mentioned that MR is not only limited to head mounted displays (HMD) as we might think of AR today due to Googles Glasses, Oculus Rift, Microsoft HoloLense and many others. Besides those HMDs other monitors like tablets can also be used (handheld displays). Also projections of a beamer (projection displays) onto real world objects open the door to MR applications and use cases.[160]

The first HMD appeared already back in 1992. Caudell and Mizell described the use of a device with a head mounted see through display to support manufacturing activities in the aircraft industry which was able to display e.g. diagrams overlaid on real world objects.[161]

Google's glasses were a resurrection of this technology and created a new hype around this technology when it was released in 2012. This initial hype, especially for industrial use declined fast due to the gap between the promised specifications and the real world performance and was over in the beginning of 2015 when Google announced the end of its AR - glasses program.[162]

Since the reintroduction of Google Glasses the applications in the manufacturing industry using MR devices seemed to achieve soon a level of reasonable industrial usage. With the increasing number of CPS connected to a ubiquitous IoT the possibilities and use cases are numerous. But the transformation of the applications from investigative and research state to real industrial applications has not yet taken place.

Two issues arise when applying AR in the industrial field. The first being the availability of solid models of the industrial objects, facilities and the surrounding environment and secondly the dynamic rendering of all those solid models is vital for its use but it imposes high computation loads.[163]

The problem is not the processing speed due to advances in processor technology but often the limited space for embedding chips with sufficient power as well as sensors into the

[158] Milgram, P.; Kishino, F., P. 3
[159] Furht, B. 2011, P. 3
[160] Azuma, R. et al. 2001, P. 34
[161] Caudell, T. P.; Mizell, D. W. 1992, P. 660
[162] *Glass Almanac 2015*
[163] Furht, B. 2011, P. 651

devices. The energy consumption of those devices is also limited which makes the devices still not very attractive for a broad implementation.[164]

Additionally, to the classical hardware and software companies' also new players emerge. Exemplarily one specific can be mentioned, namely Daqri. They are developing a system that is specifically designed for the industrial use in contrast to the other manufacturers which developed their systems focusing on the end consumer market and only secondarily enabling industrial applications. This approach facilitates to focus on increased operating hours and improved performance and therefore justifies a higher price which end consumers would probably not be willing to pay. Additionally, the design is not that much restricted in terms of convenience and appearance. A successful implementation especially for the industrial use is therefore getting closer to realization. Figure 2-32 shows the helmet developed by Daqri.

*Figure 2-32 Daqri AR helmet[165]*

#### 2.7.6.1 Use cases and applications

In the following use cases and fields of application are presented and their level of maturity will be discussed.

##### Maintenance tasks

In the production process many tasks are very complex and cannot solely be taught in class rooms. This problem can only be solved by getting real work experience and knowledge by being out in the field. Especially in the maintenance area there are on the one hand those easy tasks which can be fulfilled by following a predefined checklist where on the other hand is the highly complex tasks of failure analysis where the ability to compare the current situation with former similar ones and drawing the right conclusions is necessary. A big part of this special knowledge is tacit knowledge where technicians are not able to communicate or don't even really know of knowledge they gained over the years.[166]

By recording maintenance activities and the subsequent analysis of this processes the tacit knowledge can be gathered and then provided directly on site to novice technicians performing the maintenance tasks with little experience. This enables one application like

[164] Furht, B. 2011
[165] *Daqri International 2016*
[166] Haase, T. et al., P. 28

the support of maintenance personal of the customer of a machine manufacturer by remotely guiding the personal on site through a maintenance task. With the collaboration of the maintenance expert of the machine manufacturer using the transmitted audio and video signal to a control room at the manufacturers site those tasks can be supported easily.

The Knapp AG already developed such a commercially distributed HMD system as it can be seen in Figure 2-33. They solved the problem with the limited processing power and energy provision with a vest containing a portable PC and a battery pack providing sufficient capacities.[167]

*Figure 2-33 Knapp KiSoft WebEye[168]*

### Service tasks

The use of MR can also be expanded to other activities like presented in Figure 2-34. It shows an application presented by BMW. In the shown case the worker gets instructions how to dismantle the cover of the motor block. This application is still in the development phase but the figure was first published already back in 2011.This also represents the big gap between the expectations and the real life introduction due to the limited capacities of the different devices so far.[169]

*Figure 2-34: AR - BMW[170]*

### AR in Product Development and Design Review / Evaluation

A difficulty in the product development stage is the integration of experts and customers into the design phase. The feedback provided by those two parties is necessary to improve

[167] *Knapp AG 2016*
[168] *Knapp AG 2016*
[169] Abele, E.; Reinhart, G. 2011, P. 149
[170] Abele, E.; Reinhart, G. 2011, P. 149

the first time right quality and to include the features desired as well as changing the appearance to fit the product to the needs of the customers. The lack of participation in the development stage can be overcome by the intuitiveness represented by AR technologies by introducing input devices and input approaches that promote natural, efficient geometry creation and manipulation using hands, speech and gestures. Being able to visualize and interact with the future product enables group discussions and brainstorming among a number of designers that are needed during the early design stage. Additionally, the designers can benefit from the reviews from the planners and engineers based on the experience of the following production steps.[171]

In Figure 2-35 a use case of VR at the airplane manufacturer Embraer is shown. They are using a semi-stationary device to support the developers, designer and engineers in the product development phase. The investigated part is virtually modeled on the floor using the patterns on the floor as a reference for its position. At Embraer this device is also used to show high level customers the interior of their ordered planes. By one click the color of the leather seats can be changed and other parts can be edited as well enabling the customer to experience his future product already in the design phase.[172]

*Figure 2-35 MR at Embraer for Product Design, Review and Evaluation[173]*

### Processing and assembly process

Borivoje Furth analysed different research papers on how to use AR within the processing and assembly process and identified several applications how to introduce AR in these two areas. As the material processing field is very machine centred and only a few human factors are involved the papers investigated showed that AR is limited to training and for process condition monitoring purposes. [174]

In the assembly process the manipulation of the required parts is restricted by limited accuracy and speed during the movement and positioning. The capability of the technology to perform sufficient movements in respect to interoperability with the user and the virtual

[171] Furht, B. 2011, P. 653
[172] *Canon Inc. 2016*
[173] *Canon Inc. 2016*
[174] Furht, B. 2011, P. 656–660

part is limited to assemblies and use cases with little complexity and therefore the benefits implementing this technology in the respective fields are limited. [175]

As already mentioned there are also solutions out in the market which are semi-stationary like the one at Embraer. This reduces the field of applications tremendously whereas the level of maturity in this case is far more advanced. This is due to the lack of limitations already mentioned above regarding the size of the device, the corresponding computing power as well as energy consumption of those HMDs due to the connection via cables to a stationary PC.

As an alternative to the HMDs, stationary or mobile, the use of smart devices has to be mentioned. Adhani showed in his research that the use of handhelds, 65%, (in this case Smartphones, Tablets and PDAs) in the field of AR exceeds projectors (15%) and HMDs (25%) multiple times. [176]

The level of maturity of the technology using these devices is demonstrated by Dexter Lilley in an interview conducted in February 2016. The COO and Executive Vice President of Index AR Solutions states that he and his company already realized almost 50 projects using AR applied on off the shelf tablets. He also thinks that 70 - 80 percent of the AR applications can be realized with standard devices like smartphones and tablets. With their AR applications they realized a 50% reduction in training time and efficiency gains in other use cases like inspections.[177]

#### *2.7.6.2 Implementation hurdles*

Although the idea of AR is already quiet old, still some issues are present that inhibit the widespread application of this technology. Because AR devices have to deal with a vast amount of information like the real world video stream and the additional digital layer of information, the processing speed is a crucial element. Wearing the specific devices offers the most promising applications and therefore the hardware needs to be small, light and mobile. To use it efficiently in a manufacturing environment, it also needs to be robust and the battery life should enable the device to work at full capacity for at least eight hours straight, therefore the energy storing capacities need to be improved.[178]

### 2.7.7 Smart Mobile Devices

Essential elements of I4.0 are the connection of machines and other devices to the internet and to gather data all along the lifecycle using decentralized systems. Only having this data and information is not sufficient in a globalized and mobile world we are exposed to. The information needs to be available at anytime and anywhere. The ongoing developments

[175] Furht, B. 2011, P. 656–660
[176] Adhani, N. I.; Rambli, D. R. A., P. 93
[177] *Katie Mohr 2016*
[178] Azami Zaharim 2014, P. 210

and progresses made regarding smart and mobile devices like Smartphones and Tablets are therefore a well-timed characteristic.

The use of these devices offers greater access to machine information, allows the creation of apps to support the machine operator for simplified machine operation, data acquisition, service, maintenance and diagnosis. Especially the additional built in technologies such as GPS, WLAN and cameras offer additional benefits when collecting data.[179]

Having these devices enables the user to be provided with context-based, demand oriented and decentralized information. This information is in the best case accessed via the cloud, displaying the data gathered amongst others by RFID tags installed on CPS which in combination with other devices are generating Big Data and the conclusions derived from the advanced analytics are presented in the way of augmented reality using the devices camera and screen.

#### *2.7.7.1 Use cases and applications*

In the following section some of the numerous applications already implemented will be examined.

##### Enterprise mobility platform

The supportive application of mobile devices for corporate processes enables the user to visualize all the necessary information on demand. Those devices should facilitate an effortless integration into the existing IT infrastructure, should be configurable and adaptable to the individual needs in terms of industry sector and company as well as product type and restricting the access according to the position of an employee in the company. Another important factor is the independency to the superordinate ERP, MES or any other software platform already which is already in use.

As it is shown in Figure 2-36 the company engomo developed a system which is capable of integrating data of any existing IT system, e.g. ERP, Quality control (QS), Customer Relationship Management software (CRM), Production Planning and Control (PPS) tools or any other system. The desired apps can then be configured at the company without specific programming skills due to the rather simple drag and drop interface.

[179] *Croutear, L. 2015*

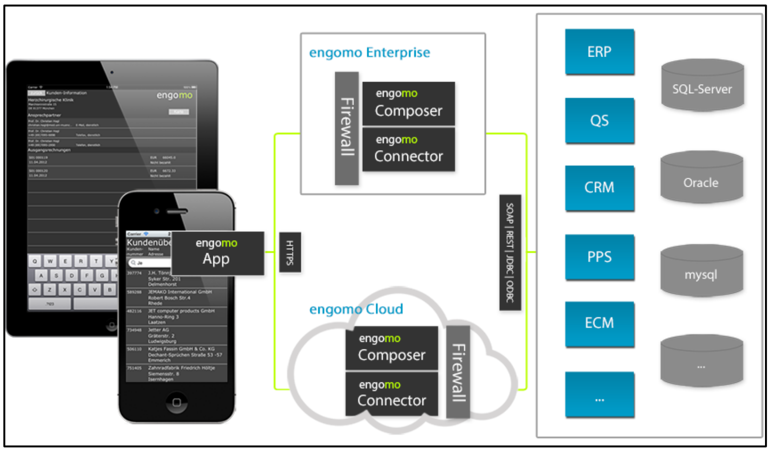



*Figure 2-36 Application as a platform*[180]

The applications developed and implemented so far have been numerous. As example for the manufacturing industry a company using this platform configured themselves an App that is capable of managing the manufacturing orders for the detailed planning. The machine operator sees the current and always updated next orders which need to be fulfilled and can decide, according to his experience, which would be the best processing sequence in terms of set up times. With this solution the company that implemented this solution was able to reduce machine downtime significantly and now they are currently working on an App to optimize the internal dispositioning and stock bookings.[181]

### Springerruf

Magna Steyer, a large company in the automotive industry, developed an App which can be used to call the jumper (extra worker that has no clear workplace assigned and can jump in if called when additional workforce is required). With this application the resources can be called to the workplace on demand to cover peaks in the workload.[182]

### Mobile dashboard & Real time alerts

The benefit of a mobile dashboard application is to make information and data available on the shop floor. The capability of providing role based information, worker vs. quality manager vs. plant manager, enabled to monitor the individually relevant key performance indicators and increase efficiency through alerts if deviations from predetermined parameters occur.[183]

### Quality Control

The use of mobile devices can improve the process of quality control, especially when it has to be done at the shop floor or off site. Until now paper had to be used to record the

[180] *Engomo GmbH 2015*
[181] *Stier, K. 2015*
[182] Weghofer, F. 2015, P. 26
[183] *Roberts, M. 2014*

investigated data which had to be digitized back at the office. This is not only inefficient; it is also prone to errors and can be overcome with the use of mobile devices.[184]

#### Instructions, Training and Checklists

Electronic work instructions can be enriched with additional information like 3D drawings and videos when compared to conventional handbooks. These medias can also be used to reduce the time required for the training of new workers or worker learning new tasks. The possibility to include checklists into these instructions can help to reduce the effort needed for subsequent quality control if stepwise in process quality control is realized.[185]

#### *2.7.7.2 Implementation Hurdles*

One major problem coming along with the implementation of mobile devices is again the security risk. Those devices are just as critical in terms of security as conventional desktops, servers and networks as they become more prevalent in the modern workplaces.[186]

Due to the smaller size of the screens inadequate mobile vision can sometimes be a problem. The applications used have to be translated extra for the view on the different mobile devices and the numerous sizes of displays available.[187]

The integration of mobile devices into the existing IT infrastructure is also considered as a hurdle while implementing them into the manufacturing processes. The biggest providers of manufacturing software are working on applications that can be integrated and only a few have already released some.[188]

### 2.7.8 Summary of the Presented Technologies

Having investigated the technologies identified in chapter 2.7 the following conclusions can be drawn. The level of maturity of the different technologies vary greatly especially when looking at the different industry sectors those technologies are implemented in. A good example for this is the AM technology which is to some extent already industrialized in the aviation industry when looking at GE but lacks of a widespread distribution in other industries. On the other hand, the automotive industry as the leading industry in the use of robots is one of the pioneers in implementing advanced robots in the assembly process. Technologies like Advanced Analytics especially when performed on Big Data can generate benefits on many different levels and the area of implementation is only relying on the data that is collected. The technologies required to enable an IIoT are already available but a realization to an extent where e.g. the product is guiding itself through the production requires a long and currently ongoing development and adoption phase. AR or VR applications on the contrary will be implemented rapidly as soon as the devices are capable

[184] *Roberts, M. 2014*
[185] *Roberts, M. 2014*
[186] *BeyondTrust Software Inc. 2013*
[187] Janardanan, R. 2013, P. 5
[188] *Ripal, V. 2014*

of performing as required in terms of operating time and computing power. The two remaining, Cloud and Smart Mobile Devices, can be seen as cross sectional technologies. The smart devices enable a new human - data interface which relies on the constant availability of the data which is more and more stored in the cloud, to leverage the full potential. These two, especially in combination with the other technologies are crucial to enable the paradigm shift as it is expected from I4.0.

The individual challenges mentioned above as well as in the specific chapters can be extended with the general challenges arising with the digitalization in the context of I4.0. Those general challenges will be investigated in more detail in the following section.

## 2.8 Implemenation Challenges of I4.0 in General

To reach the state I4.0 is promoting major changes in all the different areas have to be implemented. Those changes often come along with challenges that have to be overcome. In the following section the five biggest challenges according to the studies that have been investigated (see appendix A-10) will be discussed.

Exemplarily the BITKOM study is presented being the latest published and which is also showing the top five challenges that could have been determined during the analysis of the other studies. Of special interest in this study is that the lack of standards has only been mentioned by 36% of the respondents which is usually rated higher making it to one of the top challenges.

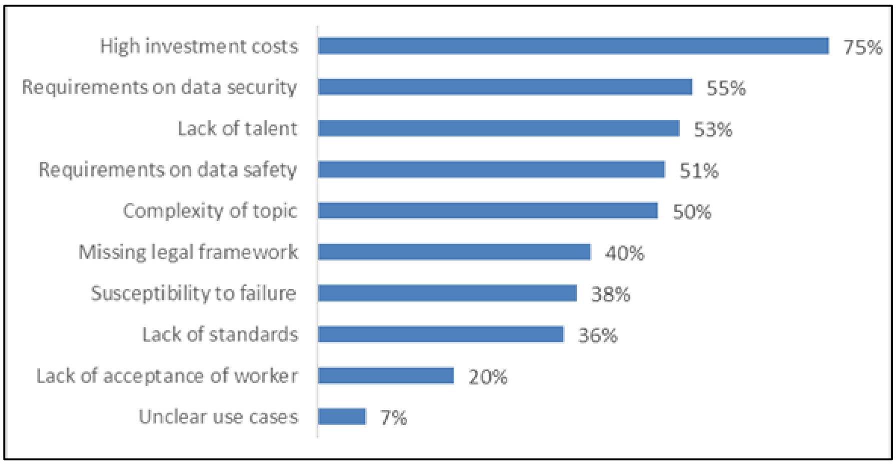



*Figure 2-37 Result of bitkom study (N=559 / 100+ employees)*

### 2.8.1 Costs

One of the biggest challenges arising when implementing I4.0 are the high investment costs as the just recently conducted study by Riemensperger 21.04.2016 shows. In this study the high costs have been the top barrier mentioned by 75% of the respondents. Wee, D. et al. 2016 identified not only the initial costs for the installation as a hurdle but also the costs arising because the underlying IT architecture also needs to be modified and adopted.

Therefore, first a clear business case has to be identified to justify the necessary underlying investments.

### 2.8.2 Cybersecurity

Cybersecurity is already today a big issue in all different industries. In 2015 already 14% of the companies have been the victim of a cybercrime attack which represents an increase of 50% compared to the number of attacks in 2014.[189]

I4.0 and the connected objects and CPS involuntarily are providing a broad target for hackers and espionage. The more access points that are created, the more the vulnerability increases. [190]

Especially for small and medium sized companies, often having only limited capacities in their IT department, the need to hand over data sets to third party providers for the analysis increases. Here another problem occurs regarding clear regulations of data ownership when working with such providers. [191,192]

In the context of IT and as it can be seen in Figure 2-37 two different terms, safety and security are recurring which need to be clarified. Safety representing the protection against accidental threats for example storing delicate information in a folder that is accessible via the internet and can therefore be accessed unauthorized or the level of the password strength. On the other hand, security is protecting against intentional threats like hacker attacks.[193]

### 2.8.3 Complexity

The complexity of the topic in general is also considered as a major implementation challenge in every study examined. Due to the fact that I4.0 affects most of the departments of a company difficulties in coordinating the actions across the different organizational units appear. The still strong silos between amongst others e.g. R&D, manufacturing, sales, IT and finance departments hinder a proper coordination of the different project which results in further difficulties regarding the development of an overall strategy. The implementation of such a strategy requires a huge commitment to push through the radical transformations required. [194]

Additional to the complexity of the topic itself the machine park and other equipment is often very heterogeneous due to the historic growth of the capacities. The diversity of

[189] Meseke, B. 2015
[190] Tate, P. 15.04.2015
[191] Wee, D. et al. 2016, P. 12
[192] Tate, P. 15.04.2015
[193] Käppler, W. D. et al. 2014, P. 23
[194] Wee, D. et al. 2016, P. 12

equipment manufacturers leads to numerous different interfaces which introduces additional complexity when the machines should interact with each other.[195]

The novelty of the topic requires an extensive know-how exchange between the different parties. Experiences made by pioneers in this field could profit from levelling the gathered know how along their value generation chain. The up- and downstream partners especially from larger companies should be integrated into the I4.0 transformation process to create a premature network which can be developed further over time.[196]

### 2.8.4 Lack of Talent

The lack of talent plays a crucial role regarding the implementation of I4.0 because in many companies only little specific know how is available. 15% of the participants in a study conducted by Riemensperger, F. 21.04.2016 intend to employ new people specifically for I4.0 topics and 11% did so in the last year.

To meet those needs new forms of interdisciplinary education needs to be established-starting in school. The demand on IT specialists, software developer, IT security experts as well as data analysts will rise once again. Policy makers have to create the basis for the education that is required already today and even more in the near future.[197,198]

Due to the lack of talent in the companies' uncertainty arise when deciding which projects are potentially differentiating enough and need to be handled in-house, which projects should best be done in cooperation with third party providers and to which extent projects should be completely outsourced. In addition, many manufacturers lack of a clear pool of internal and external resources to cooperate with regarding I4.0 applications. [199]

Especially smaller companies have often deficiencies concerning their IT department resources and therefore the CEO or other persons not fully familiar with the topic have to investigate and decide on the prospective I4.0 initiatives. [200]

Today, it's also the political and public sectors turn to motivate and promote the national industry sectors, the scientific field like universities and other researching institutes to continue their research and push developments in this area to tackle the challenges arising from the lack of talent by introducing new study programs and offering training courses.[201]

[195] Schröder, C. 2016, P. 11
[196] Geissbauer, R. et al. 2014, P. 36–42
[197] Geissbauer, R. et al. 2014, P. 36–42
[198] Riemensperger, F. 21.04.2016, P. 13
[199] Wee, D. et al. 2016, P. 12
[200] Schröder, C. 2016, P. 11
[201] Kagermann, H.; Lukas, W. D. 2011, P. 58

### 2.8.5 Standardization

A general introduction to the topic of standardization has already been presented in chapter 2.6.6 but the challenges arising during the implementation are mentioned in the following paragraph.

To fully realize a horizontal and / or vertical integration international standards need to be established. Particular problems arise during the integration of data from different sources which is crucial to make I4.0 work. The vast amount of standards which already exist today are making it even more difficult to anticipate which of those standards will prevail. This results in a hesitant behavior of the companies concerning investments in specific technologies.[202,203,204]

## 2.9 Recent Developments and Near Future

McKinsey published a study in the beginning of 2016 in which they compared their findings to a study conducted in the beginning of 2015 and were looking at the following three aspects: Perception, Progress and Problems.

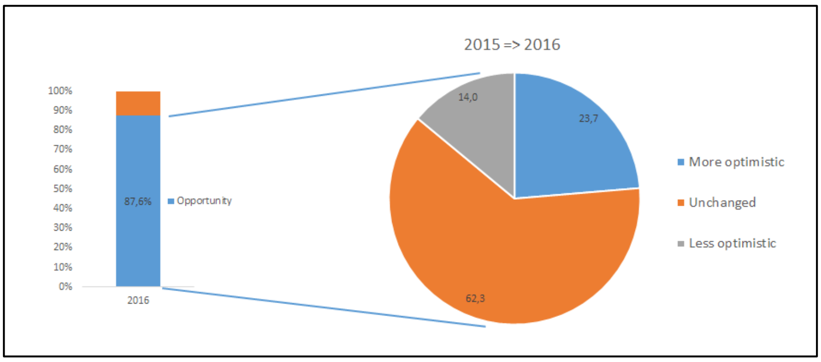



*Figure 2-38 Opinion and advancements about / of I4.0[205]*

According to this study 87,6% of the participants saw I4.0 in 2016 as an opportunity. When those participants were asked how they feel about the optimism about I4.0 23,7% were even more optimistic than back in 2015. This can have two reasons:

1. In 2015 they had not yet a clear understanding of I4.0 and the potential it implies and therefore were a little pessimistic.
2. They implemented their first applications successfully and therefore acknowledged just now the full potential a full scale implementation of I4.0 technologies and concepts might have for them.

[202] Geissbauer, R. et al. 2014, P. 36–42
[203] Wee, D. et al. 2016, P. 12
[204] Schröder, C. 2016, P. 12
[205] Wee, D. et al. 2016, P. 10

The majority (62,3%) have unchanged feelings. This can be related to not having taken any actions in the last year and their knowledge and experiences has therefore been unchanged, or changed according to their expectations.

The minority (14%) of the participants stated that they are less optimistic. This can be related to the following two reasons:

1. The expectations in 2015 were too high and the developments during the year have not met those expectations.
2. The first measures of implementing I4.0 have been established but the outcome was disappointing. Due to the short time in between the studies this might be the minor case because the real benefit might not be evaluable instantly.

As you can see in Figure 2-39 already four out of ten have already comprehensively implemented I4.0, implemented an individual project or are at least planning and testing currently. The biggest growth has been registered in the segment where the respondents are implementing individual projects with an increase from 14% in 2014 to 31% in 2015.

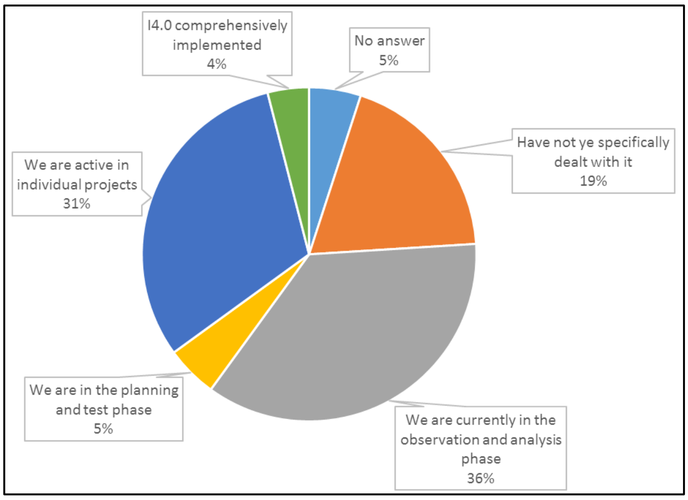



*Figure 2-39 I4.0 progress*[206]

The *Verein Deutscher Maschinen- und Analgenbauer (VDMA)* commissioned a study in which the I4.0 readiness of the investigated companies was determined. In this study a separation into three levels of readiness was done, pioneers, beginners and novices. According to this study already 2,3% of the surveyed companies are pioneers, 8,6% are beginners and 89,1% are still novices. In the following a detailed look at the classification of the beginners will be given to clarify the progress of I4.0 implementation of the different levels.[207]

A beginner according to this study integrates I4.0 in the strategic orientation of the company. Therefore, a strategy for implementing I4.0 is developed and specific indicators and key figures are in place to measure the level of implementation. Investments regarding

[206] Frenzel, U. 2015, P. 4
[207] Lichtblau, K. et al. 2015, P. 26–27

I4.0 are made in only a few sectors. In the production data is only recorded automatically only in some cases and use to a small extent. The machine park is lacking of specific requirements for a prospective expansion and adoption. The internal exchange of information as well as the exchange of information with partners is done in partial system integrated approaches and the respective IT safety and security is installed and will be upgraded steadily. The products produced at the shop floor contain the first IT based features and the staff has already the necessary competencies in some areas.[208]

The 2,3% of pioneers outperform the beginners in the different levels and the 89,1% of novices have not implemented all of the mentioned criteria for the beginner level.

This study also revealed that the differences in size of the companies also play a crucial role regarding the level of implementation. Except in the area of data driven services the differences are statistically significant as it can be seen in Figure 2-40. Statistically significant differences are considered at a level of 5% which means that the differences between the different sizes in the random sampling are very likely attributable to corresponding differences in the general base.[209]

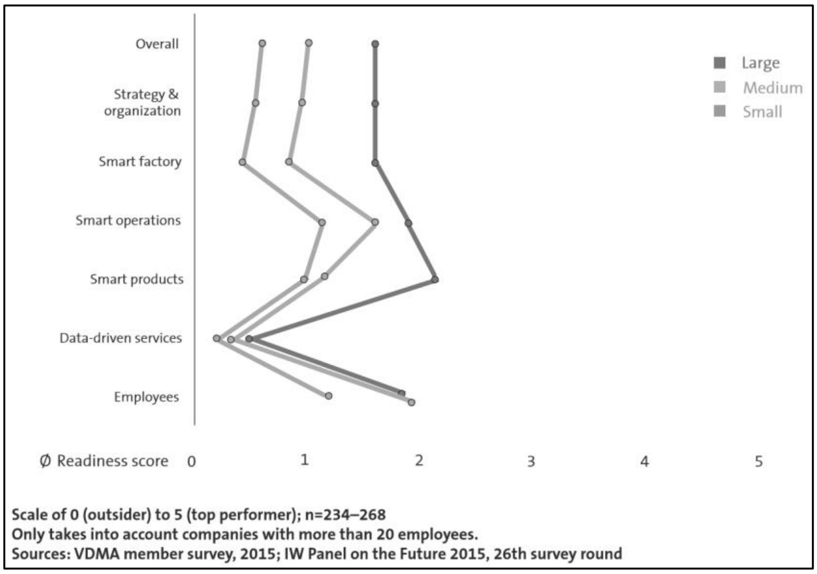



*Figure 2-40 Readiness measurement in different categories by size of company[210]*

As a conclusion of the presented findings of the studies, it can be stated that the optimism about I4.0 being an opportunity is still very high. This optimism is also supported by the increase of the implemented individual projects as shown by Frenzel, U. 2015. That bigger companies are in the lead when referring to the I4.0 readiness is due to the higher capacities and resources an obvious fact as it could be shown by Lichtblau, K. et al. 2015.

The intensity of the recent initiatives concerning I4.0 have now been highlighted and show that the motivation and the optimism is still very high and the first actions have been taken

[208] Lichtblau, K. et al. 2015, P. 23
[209] Lichtblau, K. et al. 2015, P. 27
[210] Lichtblau, K. et al. 2015, P. 28

already. Towards which direction the ongoing initiatives are heading and which departments are of special interest for the practitioners in the near future will be investigated in the following.

According to a study conducted by IDC - Insight the top five use case for I4.0 in the manufacturing industry could have been identified and are listed here: [211]

1. Product testing and quality control
2. Monitoring and optimizing internal production processes
3. Stocktaking
4. Capturing and monitoring of blanks in the manufacturing process
5. Remote control of machines and / or products

Those answers were given by 166 companies, that either plan or already implemented an I4.0 initiative. When looking at these top five use cases in more detail, you can see that the risks involved in going online are avoided as much as possible. The use cases prioritize an improved control and transparency of the internal processes with no direct need to be connected to the internet. Improving the customer relationship and establishing new business models which would require to have internet access are not ranked among the top fields of interest. [212]

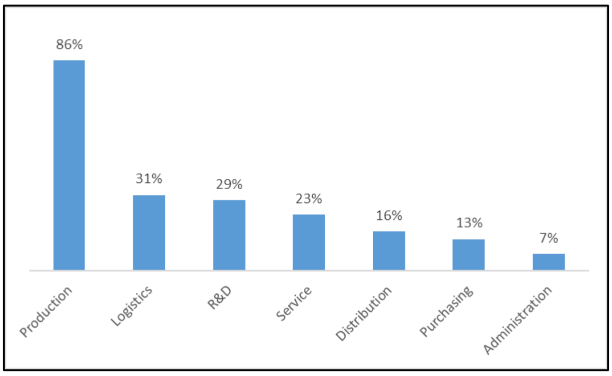



*Figure 2-41 Department of implementation[213]*

Figure 2-41 shows the departments, in which comprehensive or single projects have already been implemented, are currently tested or planned. These results support the top five use cases because it shows that the most interesting area for the questioned companies to implement I4.0 is the production department.

Another study published by Deloitte in march 2016 shows the projects which have been implemented in the last 12 months and are presented in Figure 2-42. The results of this

[211] *IDC - Analyze the Future 2015*
[212] *IDC - Analyze the Future 2015*
[213] Frenzel, U. 2015, P. 5

study are in accordance with the findings by IDC mentioned above. It can be assumed that these kinds of projects will also be prevalent in the near future.

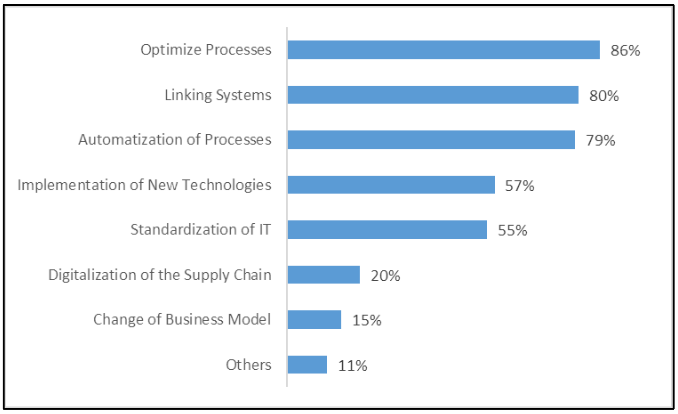



*Figure 2-42 Specific Implementation of I4.0 Projects*[214]

The top use cases are also supported by a study conducted by Bosch Software Innovations 2015. They found out that already 56% of the participants are using I4.0 related software solutions and out of those 72% are using the data to monitor machine data. The next two most prominent applications according to this study are the monitoring of process and quality data as well as the monitoring and control of logistic processes. An even greater part (66%) is planning to implement I4.0 software solutions in the near future aiming for the same use cases but instead of monitoring logistical processes the more interesting application there is the predictive maintenance.

How these intentions are going to be financed investigated amongst others a study conducted by Geissbauer, R. et al. 2014 in which 235 industrial companies have been surveyed. On average 3,3% of their annual revenues will be spent on I4.0 activities. Only two industries will make above average investments in the ongoing digitalization being the manufacturing and engineering industry (3,5% ~ 29 billion €/ year) and the ICT industry (3,9% ~ 16 billion €/ year). The overall investment extrapolated from those of the interviewed companies results in an annual investment of 140 billion € per year of the European Industry in I4.0 during the next five years.[215]

## 2.10 Findings

When you are looking at the recent developments in which areas I4.0 has been implemented so far and the intentions in which departments the investments are planned you can see that the initially presented underlying concepts are currently not in the focus of the company’s top initiatives. The necessary research and developments for establishing the required standards and platforms is relinquished to the large scale enterprises, national and international organizations which have already been active in this area.

[214] Meyer, L.; Reker, J. 23.03.2016, P. 9
[215] Geissbauer, R. et al. 2014, P. 14

The implementation in medium and smaller companies focuses therefore more on the increase of operational efficiency and on the increase of the transparency of the current processes. The technologies investigated in chapter 2.7 are predominantly also directing towards a process optimization, establishing the link between different systems and increase the level of automatization. The study conducted by Bosch Software Innovations 2015 showed that also the software solutions are targeting the optimization of the operational processes. The introduction of new technologies is only of minor importance when looking at Figure 2-42 and comparing it to the top projects focusing of efficiency gains. Software solutions and the process optimization can therefore be seen as the prior projects that are implemented today.

The implementation of the presented technologies in chapter 2.7 are mainly limited to bigger companies which are still developing their applicability in an industrial sense.

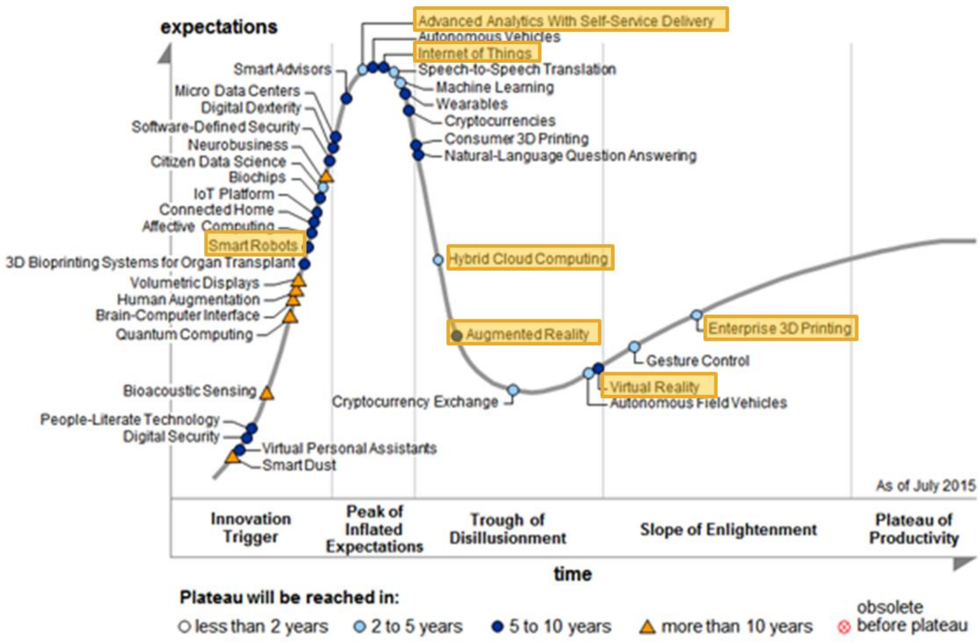



*Figure 2-43 Gartner's Hype Cycle of Emerging Technologies 2015[216]*

The Gartner Hype Cycle presented in Figure 2-43 is the graphic representation of the maturity and the adoption rate of applications and technologies and to which extent those technologies are relevant to solving real business problems. The Hype Cycle presents additionally a view of how a technology will evolve over time.[217]

The Hype Cycle is of special interest in the context of I4.0 due to the fact that most of the technologies are mapped in it. The level of attention which is given to the specific technologies should represent, when these reach the plateau of productivity.

[216] Gartner Inc. 2016
[217] Gartner Inc. 2015

In the following a review of the above presented technologies in the context of the hype cycle is presented which should identify the level of attention addressed to the specific technologies and the time period when widespread distribution and mainstream acceptance can be expected.

### Enterprise 3D printing

The current level of implementation in the aviation branch is already to some extent industrialized. The recent technological advances in this field attracted a lot of attention and therefore generated higher general interest. As it can be seen in Figure 2-43 the technology is currently on the slope of enlightenment which according to Gartner Inc. means that the technology is more understood and the benefits crystallize. More enterprises fund pilot implementations but conservative companies are still cautious. A widespread distribution implied at the plateau of productivity will be reached in two to five years.

### Augmented / Virtual Reality

Both technologies are still in the through of disillusionment. The difference between the two technologies are reasoned in the fact that the expectations of AR have been very high due to the promises the googles glass concept made but couldn't be met. Where on the other hand the public attention to the VR technology has been mildly and the recent developments and use cases show the first commercialized applications. In addition, the technological requirements for AR are higher if the expected see through head mounted displays are addresses than for the mainly stationary use of VR. But according to Gartners' Hype Cycle both technologies will reach the plateau of productivity in five to 10 years.[218]

### Hybrid Cloud Computing

The shift from the public to the hybrid cloud was mainly incited by the increasing threat of cyber-attacks. The first initiatives couldn't convince the industry of the safety and therefore more advanced solutions have to be established. In addition, the trust in the third party providers has to increase. If those challenges are met the hybrid cloud computing will reach the plateau of productivity in two to five years.

### Internet of Things

The IoT is the basic driver for the connectivity of the production networks of the future. and is today still in the phase of the inflated expectations. The hype motivated companies to establish the first immature solutions to manifest their market position already today. The realization of ubiquitous CPS still needs some further research and developments. This results in expectations of a widespread implementation of the IoT in five to 10 years according to Gartner.[219]

[218] Roth, A. 2016, P. 253–254
[219] Roth, A. 2016, P. 253

### Advanced Analytics with Self- Service Delivery / Big Data

Advanced analytics with self service delivery means to provide useful information generated using Big Data without the need of advanced programming or data analysing skills. The algorithms for the data analysis are becoming more mature and the applications are targeted towards on IT specialists. The first solutions are already on the market but still have some immaturities to overcome. The basic technology is already developed to a mature level but the implementation still lacks a little behind which leads to an expected full maturity in two to five years.[220]

### Smart Robots

Since the first small and collaborative robot was introduced in 2009 only little attention was attracted. The announcement of I4.0 directed the attention again to those robots and consequently the expectations were rising again. The recent introductions of such robots in combination with advances in their advanced hard- and software related capabilities opened up the scope for new fields of application. These innovations are still theoretical but could become reality in the next five to 10 years according to Gartner's Hype Cycle.

In the next phase interviews have been conducted to evaluate the findings of the literature review and to get further insights in the current implementation activities of the different companies and industry sectors.

[220] Rouse, M. 2016

# 3 Evaluation of the Literature Review

For the evaluation of the findings from the literature review expert interviews have been conducted. Those interviews were directed to companies that have already implemented the first I4.0 applications and therefore have gained deeper insights into these transformation processes.

The interviews were conducted using the narrative interview method. With this method the interview partner is sharing his experiences in a specific topic that had been addressed in the opening statement by the interviewer. After the interview partner stops with the explanations additional questions to get into more details on topics of special interest regarding the explanations have been asked.[221]

This method was chosen to get an understanding of the specific initiatives that have been implemented at the companies. Due to the wide scope of I4.0 and the numerous different approaches of the individual companies, a strict interview guideline would probably not have addressed the particular know how the companies have gathered during their implementation process.

The full summaries of the interviews are presented in the appendix A2 – A6.

## 3.1 Company Selection

For the selection of the companies, the following three criteria were defined:

1. The focus of the literature was pointing at discrete manufacturing processes; therefore, to be able to evaluate the findings the interviewed companies should also be in this field.
2. Due to the fact that the biggest impact of I4.0 is often connected to small and medium sized companies and the fact that the budget for R&D activities at smaller companies if often limited[222], the interviewed companies have to be of medium size (at least 50 employees).
3. To ensure that the company has a respective knowledge and expertise, they should already have implemented some I4.0 technologies or at least plan to do so in the near future.

[221] Hermanns, H. 2010, P. 183
[222] Schröder, C. 2016, P. 11

A short overview about the interviewed companies is presented in Table 3-1.

*Table 3-1 Overview about the companies*

| ***Company Name*** | **Produced goods** | **# of employees** | **I4.0** | **HQ** |
|---|---|---|---|---|
| *Test Fuchs (MISC Consulting)* | Test systems and components for the aviation industry | 400+ | Digital reflection of production process | Groß Sieghearts, Lower Austria |
| *Ginzinger electronic systems* | Electronic components, embedded systems | 80+ | Monitoring and tracing => virtual twin of product | Weng im Innkreis, Upper Austria |
| *Kresta Industries* | Plant engineering and construction | 1000+ | Consistent engineering | St. Andrä, Carinthia |
| *FILL* | Special and plant engineering | 670+ | Smart/ Connected equipment | Gurten, Upper Austria |

Two of the interviewed companies (Test-Fuchs and Ginzinger Electronic Systems) were previously identified as members of the nine leading companies in Austria in the context of I4.0 implementation by Factorynet.at, an recognized Austrian magazine focusing on recent developments in the manufacturing industry.[223]

## 3.2 Approach

Prior to the interviews an online research has been conducted to identify the implemented I4.0 applications at the different companies. In the context of the specific applications the opening statement was formulated accordingly. Subsequently the interview partner shared his experiences on the applications they implemented.

In the presentation of the interviews below the first section deals with the implemented technologies and the use cases how these technologies are applied in the company. In this part also the motivation and the reason initiating the transformation process are mentioned.

In the second part the challenges the companies were facing during the implementation phase are investigated.

The last part of each use case analysis sums up the findings and shows the area the implementations have taken place.

## 3.3 Test Fuchs

Test Fuchs is a company founded in the year 1946 and has today more than 400 employees. Their areas of competencies are the development, construction and manufacturing of test beds and components for the aviation and aerospace industry.

[223] *FactoryNet 2016*

### 3.3.1 Implemented Technologies and Use Cases

In the following the implemented technologies and concepts by Test Fuchs are presented.

#### 1. Consistent Engineering

Test Fuchs made the first steps towards consistent engineering. They managed to integrate the data provided by tool measurements into their software system generating a digital twin of the tool.

The CAD data that has been generated in the design phase of the product can directly be accesses by the work preparation department which used this data to generate the information required for the CAM process. Additional to the conventional CAM data they are now able to link the physical tool with the current tool parameters with the CAD data and the processing data (CAM). If a new part needs to be produced the operator triggers this operation and the required pre-product, the tools and the mounting devices are automatically provided to a conventional handling robot using the shuttle of the automated storage system. The robot then sets up the machine by inserting the mounting device and changing the tools if necessary, places the pre-product in the machine and via the expanded CAM data the machine knows the parameters of the installed tools and the machining process can start automatically. When the machining process stops, the part is unloaded and the machine is then automatically set up for the next part. If tool changes need to be performed a tool is put into the storage system, where previously the current parameters of the tool have been automatically detected to always represent the latest status. These parameters are directly provided to the simulation in the CAM processes. This means the data generated on the shop floor during the measurement process is automatically distributed to everyone who needs it digitally and therefore simultaneously. This lead to a reduction of set up times for the machines, an optimal tool circulation, increased the process reliability as well as the transparency of the processes. By implementing these measures, they were also able to increase the production efficiency and therefore could keep the production in house.

#### 2. Smart Mobile Devices

Test Fuchs just recently implemented mobile devices to support the assembly process of the electrical cabinet and they are currently planning to implement those devices also in the final- assembly- department.

##### a. Electric Facilities Department

Due to the fact that Test Fuchs is mainly producing lot size one up to very small batch sizes of up to 80 products per year they are confronted with a very high variance in their manufacturing processes. The electrical facilities department has just recently been equipped with tablets. Those tablets in combination with the data already generated in the planning and design phase support the workers on the shop floor during the assembly process. They see the required parts and their predetermined location on the digital representation on the tablets. This information also includes the specifications of the individual parts and other information supporting the assembly process. The provision of product specific information using the tablet lead to a reduction of failures and a reduction of processing time.

b. Final Assembly Department

Since the implementation process of the tablets in the electrical- facilities- department resulted in exceeding the expectations they are additionally planning to implement tablets in the final assembly department. The use of the tablets provides the workers always with the latest information about the product and the process. This enables late changes and reduced time to customer.

### 3.3.2 Challenges During Implementaion

Due to the fact that the implementation of the robot, the automated storage system and the software solution has been planned early enough the investment represented no specific hurdle although a double digit million investment was required. Minor challenges were the acceptance of the workers installing a robot because they feared that job losses would follow. The increases in efficiency led instead to an increase in personal due to the growth the company is facing.

### 3.3.3 Conclusion of the Interview

The loading, unloading and storage system Test Fuchs has implemented is not a I4.0 application but was crucial for the linkage of the physical and the digital world they have realized. In this case the I4.0 application was to create a consistent system which enabled a simultaneous distribution of information generated on the shop floor and providing it to the relevant persons instantly. Through the implementation of the tablets they were able to increase the efficiency by providing the right information, at the right time to the right people building on the software solution implemented for the manufacturing process.

The initiatives so far implemented at Test – Fuchs can be assigned to the top use cases identified in chapter 2.9 and therefore confirm their validity.

## 3.4 Ginzinger Electronic Systems

Ginzinger electronic systems was founded in the year 1991 and has today more than 80 employees. Their portfolio ranges from the development the serial production and manufacturing of electronic components and developing embedded systems according to customer requirements.

### 3.4.1 Implemented Technologies and Use Cases

In the following the implemented technologies and concepts by Ginzinger Electronic Systems are presented briefly.

## 1. Industrial Internet of Things

One of the basic ideas of the IIoT is to equip every object with a unique identification. This unique identification is exactly what happened to some extent at Ginziger Electronic Systems but was not the main goal nor the main driver of the implemented changes in the production process. It was the logical consequence which resulted after all the processes they were carrying out have been revaluated to stay competitive and to be able to fulfil the increasing requirements of the customers. They managed to assign each of the products produced with a unique number. In the context of mass production in the SMD (surface mount device) industry this was a challenge due to the numerous parts produced. This number is the crucial element in their new process, lasered onto the circuit board which is then equipped with the individual electrical components, they were able to ensure an individual production process for each part. When the circuit board is entering the fitting machine, this number is detected and the machine then knows which parts need to be placed onto the board without the need of human interaction changing the processing sequences of the SMD machines. This processing information is directly provided by the system generated by the development department designing the boards. This enables the production line to switch from one product to another without any modifications. After the process step is completed the part is checked which ensures that the previous step has been carried out without failures. If a failure is detected, the part automatically is excluded from the production process. This exclusion is instantly detected by the controlling system. With this information the so called production operating system[226] always knows exactly which products have been completed, how many of those have had failures and which still needs to be produced provided with up to the minute real time information about the current shop floor situation accessible anytime. The operating system also interlinks the different machines with each other so each machine knows what the other is working on enabling a dynamic production network. They also expanded this system to the inventory and the respective processes. The distribution department has also been affected by this transformation. Previously errors have happened when sending the right amount of products to the customers. It could not be ascertained which and how many parts have been sent. Now that they now the unique identity of each product they can determine exactly which parts have been sent leading to near zero failures in the distribution process. The consistency of this tracing starts already at the supplier side of the parts which are installed on the circuit boards. The incoming delivery batches get a specific number and this number is then used when attaching the parts on the board. So each party on every board can be backtracked to the exact batch delivered by the suppliers.

[226] Production operating system is the term they use for their new software solution that combines the conventionally used ERP, MES and other systems to track the different processes in a company.

2. Cloud

At the same time of the implementation of the production operating system they also switched to a cloud solution. This new operating system is provided as a SaaS which enables to interact with it through a web browser capable device like a smartphone, tablet or conventional PC.

### 3.4.2 Challenges During Implementaion

During the implementation process they faced several challenges. Before the decision for a new and unconventional production operating system was made they were already looking for a conventional ERP system for over two years. In terms of changing the software system also the physical processes had to be reconfigured and vice versa. Exceptions from standard processes presented additional challenges in how they should be implemented into the system.

Although they produced on stock for the first month after the implementation process began, they were facing delays in deliveries due to the transformation process.

### 3.4.3 Conclusion of the Interview

Ginzinger Electronic Systems established a solution which enables them to track and trace a product all along the whole internal value creation chain. From the incoming goods department down to the distribution department they are capable to locate each individual product at any time. By implementing this system, they were able to increase the revenue by one third but still have the same costs as before and were also able to reduce the throughput time by one third.

Through the changes in their processes and interlinking the machines they established a pre-version of the IIoT being able to identify each unique product as well as the parts mounted to it online and in near real time.

## 3.5 Fill

Fill is one of the international leading companies in the machinery and plant engineering industry and they have today more than 670 employees. The main field of activity is the automotive industry. A large subcontractor in the automotive industry ordered a processing line which is capable of performing all the necessary processing steps on a crankcase after the casting process. They developed and build this production line which is now used at the automotive suppliers site.

### 3.5.1 Implemented Technologies and Use Cases

In the following the implemented technologies and concepts in this processing line developed by Fill are presented.

### 1. Industrial Internet of Things

Fill realized the identification of the individual products using the concept of the Data Matrix Code (DMC). This DMC is lasered onto the crankcase and serves as the unique identification element for each product. Every piece of information generated during the processing sequence is stored using this DMC. The casted crankcases which need to be processed are delivered to the automotive supplier and they receive the information that a new batch is coming in advance containing all the DMCs for the individual crankcases and is automatically stored in the internal database. After each processing step the completion of it as well as additional information generated during the processing is stored in the database referring to the individual entities using the DMC. This enables to constantly track and trace each product in all the different processing steps.

### 2. Consistent Engineering

Due to the fact that they also had to use machines from external providers they implemented their self-developed machine workflow framework which enables them to include data from different machine and different sources. This framework gathers data from the PLCs and other sensors and devices and converts them so they can be used on their platform additionally storing it in database. Having access to all this data and interfaces enables them also to manage the workflow of the line.

### 3. Advanced Robots

To check the dimensional accuracy after the heat treatment process on the processing line an advanced robot is used. This robot is equipped with several cameras which are linked to a measurement software which is automatically detecting the required parameters and stores it to the database. Due to the limited available space only a small robot could fit. The use of such a robot facilitates measurements that had previously be done manually due to the inaccessible measurement locations. The programming of the robot is done via physical interaction and simultaneous detection of the movements.

### 4. Smart Mobile Devices – Human Machine Interface

Smart mobiles devices are also used in this production line. The crankcases are shipped in lattice boxes also having a unique identification number. This number is linked to the crankcases in the specific box. The number is scanned using mobile devices in the incoming goods department and subsequently the specific crankcases are set to the status *received* in the database. In the distribution department each crankcase again is scanned when it is put in such a box and is so connected to the specific box number and the manufacturer knows simultaneously and in advance which crankcases he will receive next.

In addition to this application another touch interface is used at the quality control section at the line. This quality control still has to be performed manually. In front of the worker a touch display is mounted and on its screen he sees the pictures of the crankcase in front of him. This picture is separated into several sections and the worker can choose in which of the sections a defect has been detected. This information is again stored in the database.

5. Horizontal Integration

The manufacturer of the crankcases also has the ability to check the current status of each individual object accessing the database from the supplier. This enables the manufacturer to access all the data he would also have access to if the line would be located at his site.

The horizontal integration is also expanded to a level as previously mentioned that the supplier already knows which batches of crankcase will arrive soon before they have even left the manufacturers factory. The information about the soon to be delivered products is sent via email in advance. This communication happens both ways as the suppliers also notifies the manufacturer about deliveries in advance when all are loaded onto the truck. The fact that both partners have access to the same database is increases the transparency and enables them to optimize the internal processes accordingly.

6. RFID

The processing centers they are selling as another product are equipped with RFID tags. The tool management as well as the measurement protocols of the tools are stored on this tag and can be recalled for correct processing. One application still in development is equipping the mounting device with RFID tags so the machine knows, which mounting device is installed and which product has to be produced and therefore can load the appropriate CNC program and start processing.

### 3.5.2 Challenges During Implementaion

The biggest obstacle for Fill while implementing I4.0 is the conservative mentality of the mechanical engineering sector regarding new technologies and therefore convince their customers of the benefits these technologies deliver. Another big issue was the lack of talent especially regarding the IT and ICT know how. This had to be developed internally over the last years and led to two new employees being specialists in these fields.

The use of other technologies which are not implemented so far are currently under investigation. Additive manufacturing for grippers and printing sand cores for the casting process in the automotive industry are relevant fields. Augmented reality applications have been tested in several projects, but those devices are still not sufficiently developed for the industrial use.

### 3.5.3 Conclusion of the Interview

With this project Fill showed that I4.0 in the automotive industry has already reached a very sophisticated level. They have realized a vertical integration beyond the company boarders receiving and sending data of the parts from and to the partner. The in-process quality control enables tracing and tracking of the individual parts using DMC, being able to constantly check the location as well as the status of the individual parts even during processing. The integration of mobile devices and touch panels into the process facilitates the concept of an industrial internet. The individual parts are therefore uniquely identified and the respective information is stored and can be accesses from anywhere. It was only possible to realize such a project by having a partner that is willing to invest in such technologies.

## 3.6 Kresta Industries

Kresta Industries (Ki) was founded in 1986 and has today more than 1000 employees in 39 locations. Today they are a complete-solution supplier for plant engineering and construction. The range of expertise starts in the R&D department, continuous with a strong engineering department and the following downstream production. On site they assemble, start up and support with service and maintenance activities.

### 3.6.1 Implemented Technologies and Use Cases

In the following the implemented technologies and concepts that are planned to be implemented at Ki will be presented.

#### Consistent Engineering

For Ki the first steps towards an I4.0 implementation considered the analysis of the internal processes. Their main objective is to increase the automatization of processes and to implement a higher level of industrialization in all departments. Due to the historic growth of the software systems currently installed they are isolated from each other. The ERP system is constrained to commercial and administrative tasks. A MES system is not yet installed and the recording of the data is done using conventional spreadsheets and text documents. This leads to ambiguities of the documentation which results in an unclear file system and results in intransparencies.

The concept is to implement a consistent software system, where all the data generated and required for a specific project is stored in one overall data set and can be accessed and used by everyone involved. Additionally, in the operative segment a system should be implemented to be able to monitor the processes digitally to be able to realize a digital supported continuous improvement process. The sales personal should also be able to work with data provided by the design department already in the customer acquisition phase to better visualize the appearance of the planned plant. In the assembly phase at the customers site the workers should be able to digitally document occurring problems during the assembly process. The overall goal is that the entire value creation chain should be able to access the required data to benefit from the work which is done by other departments.

In the engineering and design department they already implemented a new 3D - CAD system which is supported by a configurable and expandable PDM system. With this tool a systematic approach to reuse parts from historic data for new projects. The goal is a semi-automated design and engineering process. The main requirement for this CAD program in the context of consistent engineering regarding I4.0 was to be able to provide multiple interfaces to other software tools be able to connect and interlink every piece of information generated.

### 3.6.2 Challenges During Implementation

One way to prevent hurdles arising along the implementation and change process was to call in external experts for the systematic support. Another important topic mentioned for a successful implementation is the change management regarding the employees to convince them to be part of these changes.

The upcoming investments occurring have already been considered and a budget has been specifically assigned to I4.0 activities.

### 3.6.3 Conclusion of the Interview

Ki is currently in the implementation phase of a consistent engineering concept. The similarities of some projects in the plant engineering industry segment hold huge benefits when being able to reuse parts in the design and engineering phase that have already been used for previous projects. The main focus of this project is to optimize the internal processes and to try to increase the efficiencies of the design and engineering department.

## 3.7 Resumee of the Evaluation

All of the interviewed companies are primarily optimizing the current processes which is corresponding with the conclusions drawn in the literature review section and the results of the different studies investigated in chapter 2.9. This optimization is primarily done with software solutions tending towards the concept of consistent engineering. To increase the degree of automatization of the processes is also a primary task for every company followed by the standardization of the existing IT. The implementation of new technologies as it can be seen in both figures below has currently minor priority.

| Company | Activities | | | | | | |
|---|---|---|---|---|---|---|---|
| | Optimize Processes | Automatization of Processes | Standarization of IT | Linking Systems | Implementation of new Technologies | Digitalization of the Supply Chain | Change of Business Model |
| Test Fuchs | x | x | | | x | | |
| Ginzinger | x | x | x | x | | | |
| Fill | x | x | x | x | x | | |
| Kresta | x | x | x | | | | |

| Company | Technologies | | | | | | |
|---|---|---|---|---|---|---|---|
| | Big Data and Advances Analytics | Cloud | Advanced Robots | Industrial Internet of Things | Additive Manufacturing | Augmented / Virtual Reality | Smart Mobile Devices |
| Test Fuchs | - | - | - | o | - | * | x |
| Ginzinger | - | x | - | o | - | - | x |
| Fill | - | - | x | o | * | * | x |
| Kresta | - | (x) | - | - | - | * | x |

x implemented
(x) planned to be implemented
o a preliminary form is implemented
\- not iplemented / not planned to impleme
* will probably be implemented when fully

*Figure 3-1 Technologies implemented and affected activities*

The following statements resulted from the subsequent questions asked in the end of the interviews (Figure 3-1 - right).

- Big Data and Advanced Analytics is still a very complex topic, needs high investments and lacks of clear use cases with a reasonable ROI making it the least prominent technology for the companies but in literature this technology attracts the most attention.
- The companies that have not yet implemented a cloud think they will definitely implement it in the near future. It is mainly seen a supportive technology to the optimizations that need to be implemented prior to the cloud therefore the implementation remains behind.
- The application of advanced robots needs specific conditions to deliver benefits to the production process which have only been identified at Fill. All the other companies mentioned that they do not yet see a clear use case for such a robots justifying the expenses.
- The applications for additive manufacturing have so far only been investigated by Fill. To some extent they are already using it but have fully outsourced these competencies to a contract manufacturer. The other companies are in industries where additive manufacturing, if ever industrially used, needs to be further developed.
- Augmented or Virtual Reality applications are interesting technologies to nearly all of the companies, but the current development status makes them still not economically reasonable applicable.
- Smart mobile devices are already use to some extent at all of the companies. All companies think the applications and use cases for the mobile devices in the

manufacturing environment will continue to increase due to the benefits the bring along.

The results of the literature review as well as the findings during the evaluation phase interviewing the companies showed, that the primary activities are in the internal process optimization. To optimize these processes there is no direct need to implement a specific technology. As shown above most optimizations have been achieved by implementing new software solutions and reevaluation of the actual processes. Often there is hidden potential in the current processes which could be lifted applying small measures. Comprehensive implementations like they could be seen at Fill require huge commitment as well as the necessary financial and personal resources medium and small sized companies often lack of.

The findings so far will be tested during a use case presented in the next section of this thesis.

# 4 Use Case

The findings from the literature review on the theoretical background regarding I4.0 and the identified uses cases investigated in chapter two revealed the general challenges that could arise when I4.0 applications are implemented. It was shown which areas are the most interesting to implement I4.0 today and which objectives are targeted with the respective initiatives.

In the evaluation phase in chapter three actual use cases have been investigated. Those use cases also supported the findings from the previous research. The areas where the first measures are implemented by the interviewed companies were also corresponding to those from chapter two. Those areas and actions appear to be the best to start with the implementation process.

In the following chapter the use case in which the findings from the previous research were tested is presented and the learnings so far are evaluated on their applicability in real life.

During the phase of identifying appropriate interview partners for the evaluation of the findings of the literature review several companies were contacted. One particular company showed great interest in identifying potentials and introducing I4.0 at their site. After presenting the evaluated findings to the head of production they were even more interested and a collaboration to implement I4.0 measures was agreed on.

## 4.1 Company Presentation - EVG

The company EVG, short for **E**ntwicklungs und **V**erwertungs- **G**esellschaft, is located in the south of Graz. It is a globally operating company with today more than 1000 employees and more than 600 of them are working at the headquarter in Graz where the production site is located. The company was founded in the year 1948 and since then the activities have been continuously expanded.

Their core competence is the design, engineering and construction of machines that are used for processing steel wire to produce concrete reinforcement steel products. They are producing welding units with different degrees of automatization that are capable of producing all different types of steel grids as well as an automatic welding machine that produces lattice girder and other concrete reinforcing elements. Other core products are the automatic stirrup bender, straightening machines for concrete steel and cold rolling machines. They are setting the industry standards with their high level of dimension tolerances. All machines are especially designed to the requirements of the specific customer which leads to a single piece production.

One of their machines is exemplarily shown in Figure 4-1 and some exemplary parts that are produced on those machine are shown in Figure 4-2.

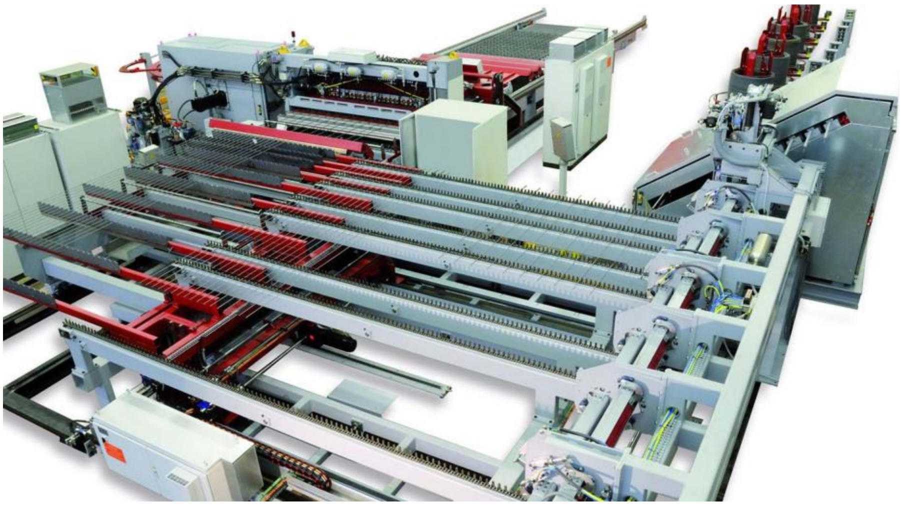


*Figure 4-1 ATT + RA-XE welding line by EVG[227]*

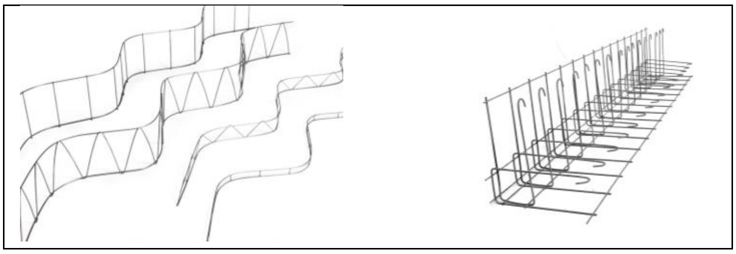


*Figure 4-2 Exemplary products produced by the machines of EVG[228]*

The primary contact for the empirical part of this thesis was the head of production at EVG. Their idea was to get take the first steps towards I4.0. The goal was to use modern technologies to support the production process and increase the production efficiency as well as the transparency of the processes. At first a use case had to be identified with the goal to optimize this process.

The objective of a process optimization is to make existing processes more effective as well as to increase the efficiency and flexibility of existing processes. The focus is to change the process procedure but maintain the current structures.[229]

## 4.2 Methodological Approach

According to Becker, T. 2008 the following procedure for the optimization of a process has been proven successful. The sequence of the procedure is presented in Figure 4-3.

[227] *EVG Entwicklungs- und Verwertungs- Gesellschaft m.b.H. 2016*
[228] *EVG Entwicklungs- und Verwertungs- Gesellschaft m.b.H. 2016*
[229] Becker, T. 2008, P. 28

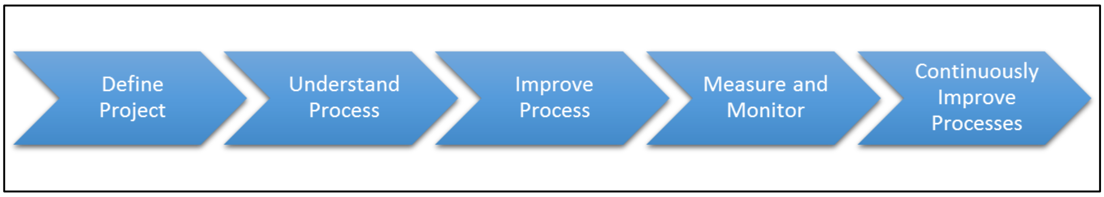



*Figure 4-3 Sequence of the Process Optimization Procedure*[230]

## 1. Define Project

In the project definition phase the responsible person for the optimization process has to be identified, the eligible use cases have to be selected and an appropriate team that will work on the improvements has to be put together. The main objectives have to be identified as well in this phase.[231]

## 2. Understand Process

The foundation of every process optimization is the is a detailed process analysis. This analysis should uncover weaknesses where the process improvement can engage.[232]

In the second phase the status quo has to be determined. The visualization of the process helps to determine sub processes and uncover dependencies. It can also be used as a benchmark to compare the optimized process to. After the As-Is state has been visualized, the process should be followed in real life to be able to eliminate possible inaccuracies and deviations. The next step in this phase is to conduct interviews to get to know the affected area in more detail and to identify the opinions and ideas of the persons involved.[233]

For the visualization of the processes the BPMN will be used because it is a ISO [234] standardized notation used for the modelling of processes. It is used to provide a notation that is understandable by any business user and it represents an amalgamation of best practices.[235] A detailed description of the symbols used in the visualization is presented in appendix A - 7.

## 3. Improve Process

In phase three the process redesign begins. This phase can be started with a clean sheet redesign and then has to be evaluated. The existing restriction should then be integrated into this new process and in an iterative process the best design should be developed. The final process then should be presented to the management and they have to be confident that every risk that might occur is managed properly. The last step in this phase is to implement the redesigned process.[236]

---

[230] Becker, T. 2008, P. 29
[231] Becker, T. 2008, P. 28–29
[232] Schwab, A. J. 2014, P. 398
[233] Madison, D. 2005, P. 67
[234] ISO/IEC 19510:2013
[235] ISO Standardization 21.05.2016
[236] Madison, D. 2005, P. 67–68

Schwab, A. J. 2014 determined the substantial steps to achieve a process optimization and those are listed in the following:[237]

- Eliminate unnecessary process steps
- Avoid redundant activities
- Avoid inspections by preventive measures
- Outsourcing to experts
- Transformation of the process layout from the functional (job shop) to the process oriented (line, group) layout
- Switch from push to pull system
- Combining several process steps into one
- Allows parallel activities
- Avoid mistakes which dictate iterative process cycles
- Avoid bottlenecks
- Reduce number of parts of an assembly

#### 4. Measure and Monitor

To ensure that the process optimization has resulted in improvements key figures have to be defined, measured and monitored. [238]

#### 5. Continuously Improve Process

In the context of this process step the improvements are monitored regularly and a person responsible for the recording and reporting has to be elected. Referring to the key figures determined in step 4 the performance of the process is evaluated. Measures for additional improvements of the process are initiated and a yearly benchmark helps to detect deviations from the predetermined target figures.[239,240]

## 4.3 Project Definition

To be ensure that everyone has the same understanding of I4.0, the according technologies and concepts, a presentation was held at the company site.

The responsible person for the entire optimization process was the head of production and the project team included the production manager, the responsible person for the MES and ERP system from the IT department and myself.

After this presentation a workshop was held and the qualified use cases described in the following have been identified.

[237] Schwab, A. J. 2014, P. 407
[238] Becker, T. 2008, P. 30
[239] Becker, T. 2008, P. 30
[240] Madison, D. 2005, P. 68

### 4.3.1 Use case 1 – Optimizing the Maintenance and Repair Procedure

The recent economic developments like the sanctions against Russia led to a reduction in demand and therefore the company had to cut one shift in the production department at the end of 2015. The lapse of this shift requires a higher machine utilization during the two remaining shifts to be able to fulfil the orders on time.

The reduction of personal did not only concentrate on the manufacturing department but included also members of the internal maintenance and service department. The personal in this department is in charge of keeping the production running as well as other service tasks in terms of building services. In this department workers with different fields of expertise like electricians, plumber and heating installers and mechanics are employed. Due to the reduction of personal only two, from previously six workers are remaining that are assigned to the production department being one mechanic and one electronic technician. The consequence to the limited capacity were long unplanned downtimes originating from an unreasonable long reaction time.

The reaction time is defined as the time between a failure occurs at a machine and the maintenance workers start with their work at the affected machine.

Due to the fact that the machines which EVG produces are specifically designed for the customer they follow a single piece production strategy. This leads to very little quantities of the same parts produced on each machine. Because of this and the historic steady growth in production capacity the machine park is very heterogeneous. Additionally, they are producing on machines from several different manufacturers and the age of the machines ranges from two to 25 years.

The machine park in the manufacturing department consists of the following types:

*Table 4-1 Machine park EVG*

| | |
|---|---|
| 4x saws | 2x grinding machines |
| 1x radial drilling machine | 1x key seating machine |
| 3x lathes | 9x milling machines |
| 6x drilling machines | 2x indoor cranes |

All the machines are different in size and have different features which means that there are hardly any redundant machines. To shift production from one machine to another, if possible, requires a lot of preparation work. To switch the production between the machines due to planned downtimes require little effort because this is planned in advance. Switching production due to unplanned issues is, because of the heterogeneous machine park, a very complex task. This shows the necessity of a short reaction time if a machine is down unplanned.

The idea addressing this problem was to minimize the reaction time and therefore increase the machine utilization.

### 4.3.2 Use Case 2 – Tool Management

The historic growth of the machine park and the resulting heterogeneity has an additional consequence. The tools that are used on the different machine have been changing over time which lead to a dramatic increase in the tool inventory because in the past they have been ordered in higher quantities. In addition to this also the tools have become more advanced. Today only tools with internal cooling channels are used on the machines but the tool inventory still holds numerous older tools without those cooling channels.

Another aspect that has to be considered is the tool crib procedure. All tools are separated into two categories. Tools that are assigned to a specific machine and tools that are used only for specific orders and processes. The latter have to be picked up at the tool crib. The machine operator hands over his personal ID tag which is then exchanged with the tool. Is the tool no longer required he returns it and it is exchanges with the ID tag. This process is not very transparent and sometimes leads to overstock because tools are reordered without any necessity. If the tools would be returned on time this reordering and the resulting overstock could be avoided.

The specific tools that are constantly on the individual machines are already tracked using the production data acquisition (PDA) system. Due to the configuration of this system a change to include the variable tools would require excessive programming and reconfiguration. Due to the limited capacities of the IT department this is currently not an option to overcome this problem.

The use case would include the identification and subsequent elimination of the unneeded tools from the tool storage system. In addition to this, a system capable of tracking and tracing the movements of the variable tools should be implemented.

### 4.3.3 Decision on Use Case

The conclusion of the workshop was that these two might be the right use cases to implement the first I4.0 measures. The fact that the first use case would results in a long term impact for the company whereas the second only has a momentary large followed by an ongoing smaller impact the focus was set to the first use case. If this could be implemented successfully, the second use case should be attempted subsequently.

## 4.4 Understand Process

The next step according to the procedure presented in chapter 4.2 is to understand the current process. According to the PM they recently made changes to the maintenance process where they introduced a so called service ticket. To better understand the reason for the recent changes and the current challenges, the previous process was explained briefly by the PM and is presented in the following.

### 4.4.1 Previous Process

Just recently the company installed a so called ticket service for the maintenance personal so they are now able to see the next tasks they are assigned to. Previously there was no clear system to determine the importance as well as the sequence of the tasks they were assigned to next. The reason for installing a so called ticket system was, that during the maintenance personal was working on a specific machine it happened that other workers approached them and mentioned that their machine also had problems and needs to be checked. Due to the lack of a proper information system, the maintenance workers sometimes forgot the sequence in which they were approached by the machine operators and therefore the sequence of the tasks to perform next. This resulted in little transparency for the maintenance workers and subsequently led to long machine downtimes due to unclear task assignment.

With the implementation of the ticket system the lack of transparency in those service requests was reduced.

### 4.4.2 Overview Status Quo

To really see the problems occurring in the real life application of this process the day to day activities of the maintenance workers (MW) were monitored. Two consecutive days I accompanied the MW and could investigate the specific challenges they were facing.

Currently the machine operator who is facing a problem first has to report the failure at the PDA terminal and subsequently has to look for the production manager (PM). The PM then contacts the administration and assigns a specific priority to the required maintenance task according to the importance of the machine. In the next step the administration generates a ticket at the enterprise resource planning (ERP) system. When the MW is finished with their current tasks, they return to their office where they check the list of tickets generated in the meantime. If there are no high priority tasks pending they decide according to their experience which of the listed tasks is the most important and start working on it.

#### *4.4.2.1 Visualization of the Current Process*

Due to the fact that different departments of the company (manufacturing, maintenance, administration) were involved in the process, a tool capable of visualizing the information flow as well as the sequence flow between the departments was required. The Business Process Modelling Notation (BPMN) provides these capabilities and therefore was selected to visualize the process. An overview of this process is presented in appendix A – 8.

##### Machine operator

The process starts when a failure occurs at a machine. The first step the operator has to do is to go to the next PDA terminal and report the failure of the specific machine. This process stops the processing time of the current order and the starting point of the downtime of the machine as well as the machine ID is recorded. As a next step the operator has to look for the production manager. Due to the fact that the production manager is not always in the control room this sometimes consumes a significant amount of time.

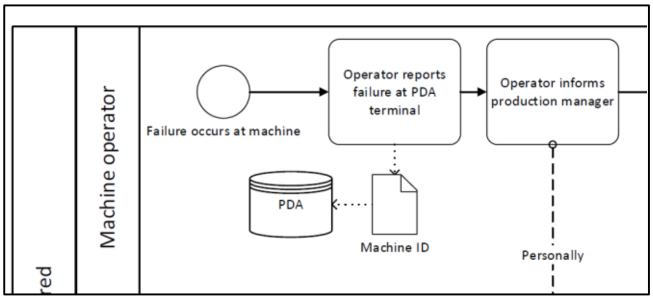



*Figure 4-4 Tasks of the machine operator (1)*

## Production Manager and Administration

When the production manager has been contacted he then calls the administration and requests a so called service ticket and shares the information he got from the machine operator. The ticket is then compiled by the administration in the ERP system, the respective maintenance personal (MP) is assigned to the ticket and the production manager contacts him via telephone.

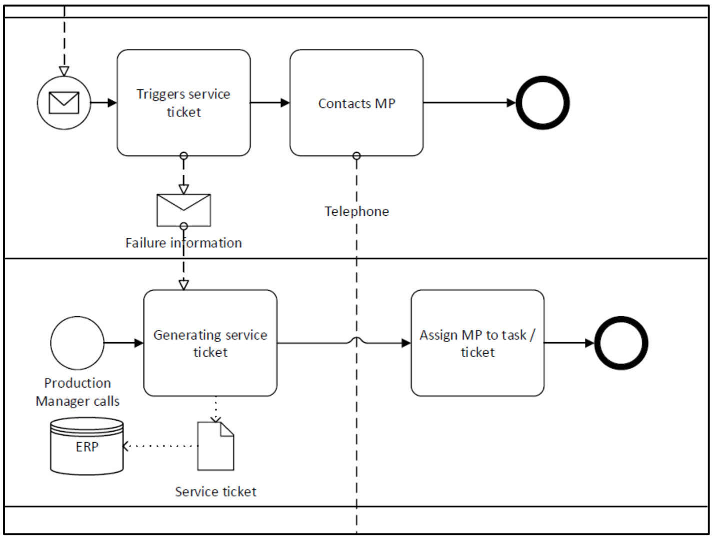



*Figure 4-5 Tasks of the production manager / administration (1)*

## Maintenance personal

At this point the MP first notices that a machine is down. Because the production manager has no authority to direct the MP he continues the current task. After the current task is finished, the MP has to report this at a PDA terminal.

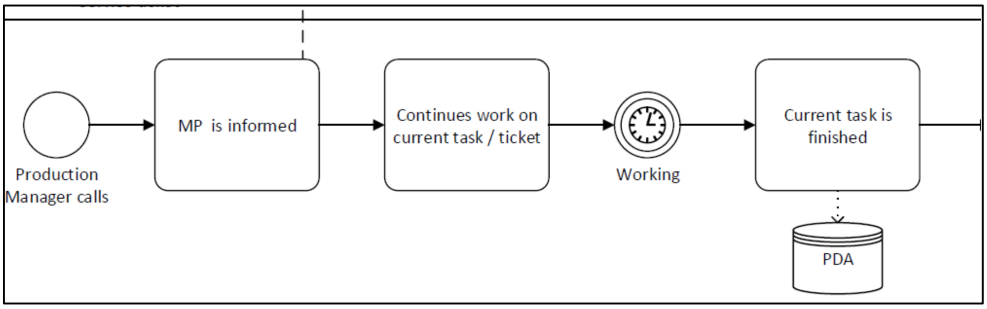



*Figure 4-6 Tasks performed by maintenance personal (1)*

The next task of the MP is going to his office where he checks for the next tickets assigned to him provided by the ERP system. He then accepts the next tasks and assigns the following time to the respective machine using the PDA terminal and goes to the machine and start the repair activities.

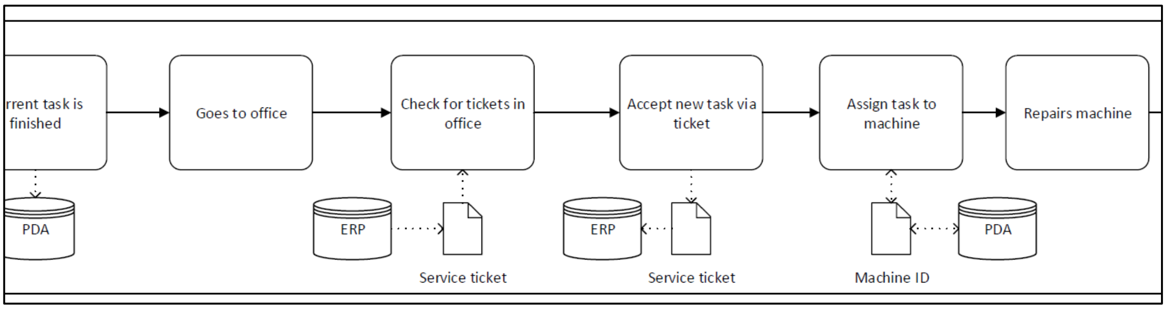



*Figure 4-7 Tasks performed by maintenance personal (2)*

When the repair process is finished and his tasks is completed he triggers the re-start of the machine, reports to the PDA and closes the ticket in his office and he can start to work on a new task.

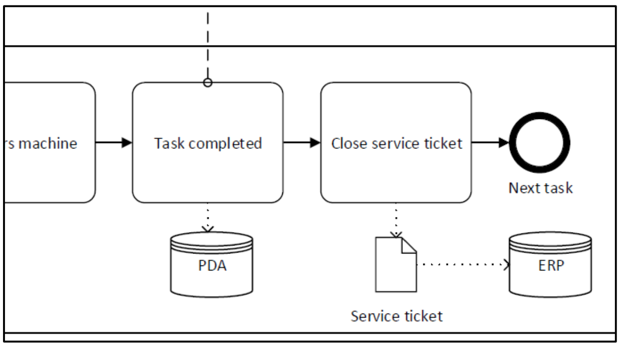



*Figure 4-8 Tasks performed by maintenance personal (3)*

The last action is performed by the machine operator who reports the end of the downtime and assigns the machine to the next order at the PDA terminal and starts again his work.

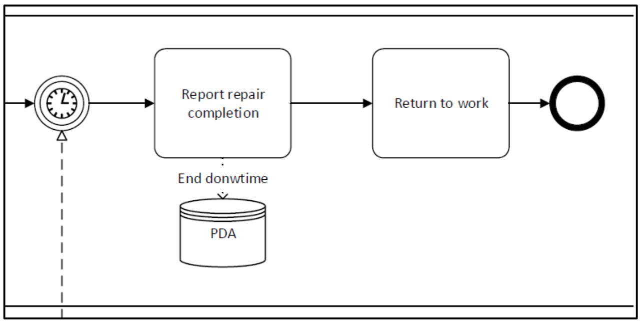



*Figure 4-9 Tasks performed by machine operator (2)*

#### *4.4.2.2 Analysis of current process*

For the detailed analysis of the process the recordings of the downtimes of the machines in the PDA system, the starting times of the ticket system in the ERP system and the times from the PDA system when the MW signs onto the specific task were requested. With this data the current reaction time had to be determined to get a clear idea of the actual situation.

Due to the fact that the ticket system was just recently installed (July 2015), the acceptance of the MW is not yet very high. Although they see the benefit of the system, being able to see the next due tasks and their sequence how they were reported, the overall process is too complex and takes a lot of time for documentation and other activities. The lack of acceptance is also reflected in the time recordings represented through enormous inconsistency.

#### *4.4.2.3 Analysis of Data Sets Received*

The data sets with the highest quality were the downtimes recordings generated by the PDA system. This can be ascribed to the fact that the machine operator doesn't want to have downtimes assigned to a specific order he is working on when the failure occurred. If the operator wouldn't report the failure of the machine at the PDA system, the time consumed for repairing the machine would be assigned to the respective order leading to inaccuracies in the time recordings for the orders. Additionally, the PDA terminals are spread evenly throughout the production facility and therefore the operator is able to instantly report the failure.

I could notice that the data sets generated by the PDA system representing the hours the MW worked on the machines is not very accurate. Because the MW is also assigned to other locations than solely the production facility, which are often not sufficiently equipped with PDA terminals, it sometimes results in inaccuracies of the recorded times.

The data set received representing the ticket times was the most inaccurate. Sometimes the starting time of the ticket was three days after a failure occurred at a machine even if the repair process only took several minutes according to the PDA data of the machine. The reason for this discrepancy between the point when the failure occurred and the time the ticket was generated is the difference in working hours of the administration compared to the workers at the manufacturing facility and the fact that the administration the only instance that is capable of generating the service tickets.

Another problem occurred correlating the different data sets with each other. The list of the downtimes of the machines generated by the PDA system had no clear identification. The only information stored was the name of the machine, the type of failure and the date and starting time as well as the duration. An extract of the received data can be seen in Table 4-2. Additionally, there were cases included in this list were no MW was required and the machine operator was capable of solving the problem without any help.

*Table 4-2 PDA - machine failure - data set*

| Macine | Failure Type | Day | Duration | Start | End |
|---|---|---|---|---|---|
| NC-Drehmasch. D41 | D41 Störung und Service | 20150707 | 0,41 | 0600 | 0624 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150707 | 0,36 | 0643 | 0705 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150810 | 0,57 | 1411 | 1445 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150814 | 1,63 | 1714 | 1852 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150826 | 0,34 | 1928 | 1948 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150907 | 0,83 | 1309 | 1359 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20150924 | 0,52 | 1805 | 1836 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151001 | 1,55 | 1125 | 1258 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151002 | 1,93 | 0509 | 0705 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151007 | 2,08 | 1508 | 1713 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151019 | 0,29 | 0827 | 0844 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151104 | 0,93 | 0628 | 0724 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151104 | 0,77 | 1623 | 1709 |
| NC-Drehmasch. D41 | D41 Störung und Service | 20151201 | 0,65 | 0810 | 0850 |

The data set extracted from the PDA regarding the MW hours at the specific machine revealed no further useful information. You could only determine who of the MW worked at the machine. The so called response number just addresses the machine affected and therefore provides no further information than the name in the third column of Table 4-3. Additionally, the date, the time of start and end of the MWs work as well as the duration is recorded.

*Table 4-3 PDA - MP assigned - data set*[241]

| PERSNR_NAME | Response Nr. | Description | AG_POS | Date | Year-Period | Start | End | Duration |
|---|---|---|---|---|---|---|---|---|
| [redacted] | 12054050 | Keilnutziehmasch. H71 (Balzat) | 10 | 20150701 | 201507 | 0600 | 1346 | 7,27 |
| | 12054050 | Keilnutziehmasch. H71 (Balzat) | 10 | 20150701 | 201507 | 0606 | 1400 | 7,40 |
| | 12058823 | Säge K012 | 10 | 20150701 | 201507 | 1347 | 1500 | 1,22 |
| | 12054033 | 5119051 BAZ Deckel Maho (F11) | 10 | 20150702 | 201507 | 0605 | 1145 | 5,17 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150703 | 201507 | 0653 | 0952 | 2,98 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150706 | 201507 | 1416 | 1530 | 1,23 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150706 | 201507 | 0922 | 1019 | 0,95 |
| | 12058824 | Säge K013 | 10 | 20150706 | 201507 | 1344 | 1416 | 0,53 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150707 | 201507 | 0607 | 0756 | 1,82 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150707 | 201507 | 0605 | 1131 | 4,93 |
| | 12054048 | F94_2007_Langfräsm.Soraluce | 10 | 20150707 | 201507 | 1131 | 1319 | 1,80 |
| | 12054051 | Langfräsm. F86 (SHW UF6) | 10 | 20150707 | 201507 | 1337 | 1500 | 1,38 |
| | 12054036 | BE. Zentrum F22 | 10 | 20150708 | 201507 | 1355 | 1409 | 0,23 |
| | 12054036 | BE. Zentrum F22 | 10 | 20150708 | 201507 | 1304 | 1354 | 0,83 |
| | 12054043 | F20_2007_BAZ_Reckerm.RBZ850 | 10 | 20150708 | 201507 | 1343 | 1600 | 2,28 |
| | 12054045 | F71_2008_Bohrwerk_Union_KC110 | 10 | 20150708 | 201507 | 1150 | 1343 | 1,88 |
| | 12054045 | F71_2008_Bohrwerk_Union_KC110 | 10 | 20150708 | 201507 | 0732 | 0937 | 2,08 |
| | 12054047 | F81 Bohrwerk TOS (511604) | 10 | 20150708 | 201507 | 0937 | 1150 | 1,72 |
| | 12054051 | Langfräsm. F86 (SHW UF6) | 10 | 20150708 | 201507 | 0612 | 0646 | 0,57 |

[241] columns blackened due to privacy issues of the affected persons

As already mentioned, the last data set that received was containing the ticket information and was for this analysis of no further use. An extract for documentation can therefore be seen in the appendix.

#### 4.4.2.4 Results of Data Analysis

In the following phase a comparison between the two data sets presented in Table 4-2 and Table 4-3 has been done to determine the current average reaction time. This reaction time represents the time between a failure occurs at a machine and the MP starts working on it. It is calculated by comparing the time the failure of the machine was reported at the PDA system and the time the MW has signed onto the machine also using the PDA system.

The evaluation of this data had to be done manually due to the reasons mentioned in chapter 4.4.2.3. The results of this evaluation are presented in Table 4-4 and can be seen as the initial value of the performance indicator that is planned to be optimized.

*Table 4-4 Average reaction time*

| *Month* | *Average reaction time [hh:mm]* | *Events* |
|---|---|---|
| *July* | 01:00 | 17 |
| *August* | 02:13 | 9 |
| *September* | 00:41 | 7 |
| *October* | 00:43 | 11 |
| *November* | 01:13 | 10 |
| *December* | 01:30 | 13 |
| *Sum* | 07:23 | 67 |
| ***Average*** | **01:13** | **11** |

The analysis showed that the average reaction time since the introduction of the ticket system in July 2015 (the period the data was investigated) amounted to 1hour and 13 minutes.

The investigated period was limited to the six months prior to the reduction of the third shift. This limitation is based on the fact that the maintenance team has already been reduced to the current status in July 2015 prior to the reduction of the machine operators and other production department staff in December 2015.

The time recordings prior to July 2015 were of no special interest for the head of production because back then four MW per shift were dedicated to these tasks. In addition, the MW have since the reduction of the third shift different working hours than the production department staff making it difficult to compare the two different times.

The visualization of this process using the BPMN notation (see appendix A – 8) has been shown to the production manager and the head of production and they were also questioned about the problems they registered in this process. In a workshop evaluating the findings gathered for the current process the following four main problems have been identified:

1. The PM is not constantly at the control room and the worker whose machine is down most times has to look for the PM to trigger a ticket
2. The PM has no authority to issue directives to the MW / only by priority of ticket
3. The MW only sees the tickets at their office which leads to unnecessary waiting time and non-productive time walking to and from their office
4. Complex and unclear flow of information due to the necessity of contacting the administration

With these problems at hand it was clear, that introducing I4.0 technologies could have the desired effects to reduce the reaction time and therefore optimize the maintenance process.

## 4.5 Improve Process

As the analysis showed and the previously identified problems in chapter 4.4.2 indicated, the flow of information as well as the whole process is too complex and inefficient.

#### *4.5.1.1 Objectives*

After presenting the findings of the analysis to the involved persons, the following objectives for an optimized process were derived in a workshop:

1. Reduction of the parties involved (a solution without the need to contact the administration should be established)
2. The affected parties should be informed instantly and simultaneously after a failure occurs.
3. To increase the discipline regarding the ticket system a ticket should be generated automatically so it can be used right away.
4. The production manager should be able to re-arrange the tickets according to their importance.
5. The non-productive time of the MW walking to and from their office should be reduced to a minimum and therefore increase the availability of the MW.
6. The operator of the machine should not have to look for the production manager.

By analysing these objectives, the use of mobile devices obtrudes. The requirement to provide decentralized, context- and needs- based information as well as the possibility to manipulate the information on the go can be best fulfilled using smartphones or tablets.

#### *4.5.1.2 Requirements*

The head of production being the responsible person for this project determined some requirements which have to be met when implementing a new solution. Because this project should present the possibilities and the benefits of implementing I4.0 in a small use case the effort for the implementation should be confined. As a result, the following requirements were defined:

- Little costs if implemented (max. 10.000€ for the implementation)

- Should be able to be integrated into the existing IT infrastructure (ERP/ PDA system)
- Little programming effort due to limited capacity of the IT department
- Devices should be capable of withstanding rough environmental conditions

#### *4.5.1.3 Solution*

The requirement to be able to integrate the solution into the existing IT system led to the conclusion that the PDA provider might be capable of providing such a solution. Due to the fact that the PDA system is a little outdated and the inclusion of the ERP system of another provider is necessary the programming effort for this application would result in exceeding the maximum costs by far.

Another, independent provider had to be found. After some research such a platform was found. They provide a system that can be integrated into most of several IT systems of the different business software provider. The software is on top of the others and is capable of accessing the different data bases fulfilling the requirement of being able to be integrated into the existing IT.

Once the platform is installed, individual applications can be created with very little effort based on the Drag & Drop principle.

Due to the fact that this system is provided based on licensing, the programming can be done with little effort and the installation of the system is done by the experts of the providing company within a few days, the intended costs for implementing this solution would not be exceeded as it can be seen in Table 4-5.

*Table 4-5 Estimated costs for implementing new system*

| | |
|---|---|
| Installation of system on site | 5.000 € |
| License for device / month | 20 € |
| # of devices | 5 |
| Yearly licensing costs | 1.200 € |
| Costs 1st year | 6.200 € |

This cost information has been estimated by the platform provider and is still a little depending of the actual installation effort at the company. The maximum costs have not been met and there is still a budget for the programming of the required application on the platform.

### *4.5.1.4 Overview of Optimized Process*

The next step was to redesign the process with the objectives and requirements in mind. In appendix A – 9 the overview of the new process is presented and will be explained in detail in the following.

#### Machine operator

The initial start event is here again the failure of a machine. The machine operator has to report the failure at the PDA terminal like at the current process, but now he also has to choose which one of the MP he needs. If the machine operator doesn't know what type of failure occurred, he can also choose to contact both.

Additionally, an automatically generated failure trigger is generated when the operator sets the machine status to failure.

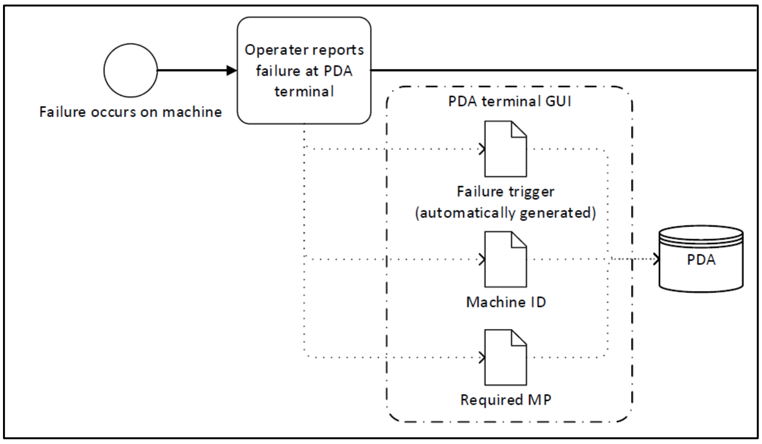



*Figure 4-10 Tasks performed by machine operator (new1)*

#### Platform

The next phase of the process needed the administration department in the previous process but will now be replaced by the platform which has the capability of communicating with the PDA as well as the ERP system.

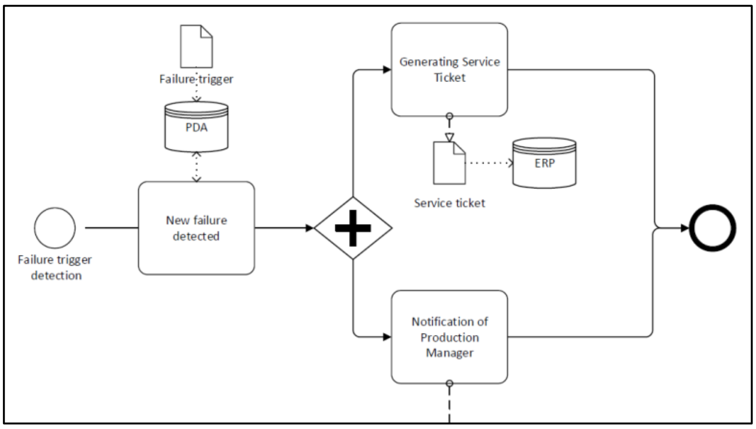



*Figure 4-11 Actions performed by platform (new1)*

The failure trigger set automatically when the machine operator sets the machine state to failure in the PDA system is checked every minute by the platform. If a failure (and consequently a failure trigger) is detected, the platform automatically informs the production manager and generates a tickets in the ERP system according to the information provided by the PDA data.

### Production Manager

The production manager is notified via push messages provided by the smartphone (like known from the SMS notification). A list of the current tasks of the MPs as well as a list of the orders in combination with the respective priorities on the affected machine is provided to the PM by the platform using the information generated before at the PDA and ERP system. This information enables the PM to decide whether the MP should finish the current tasks or if they should immediately check for the reported machine. As soon as the production manager determines the priority, the MP is informed instantly.

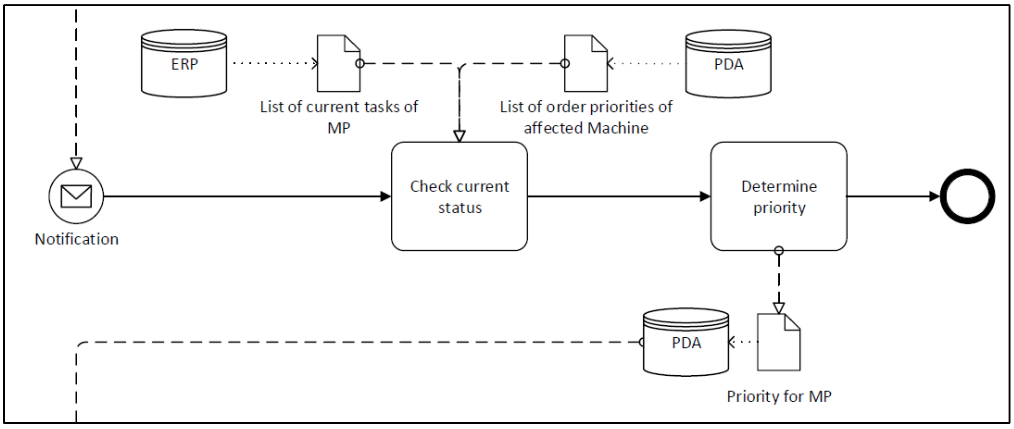



*Figure 4-12 Tasks performed by the production manager (new1)*

### Maintenance personal

The respective MP is also informed by a push notification on his smartphone and at first he checks the priority of the incident. If the priority is “High” or “Normal” he can continue the current tasks and check the machine according to the predetermined actions considering the priority level.

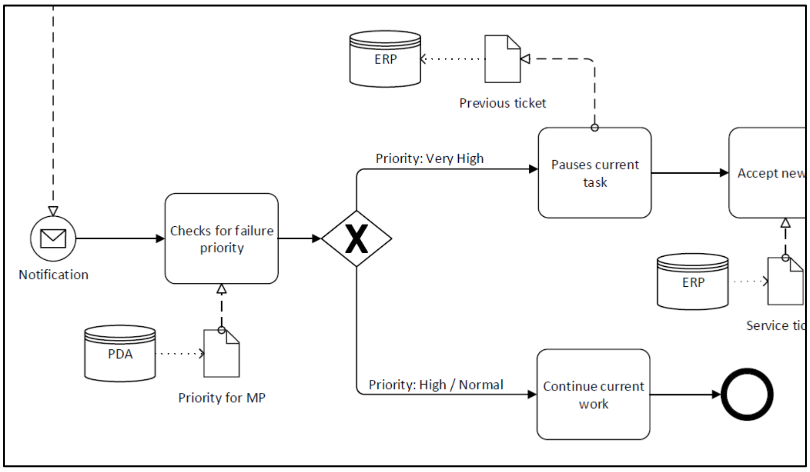



*Figure 4-13 Tasks performed by MP (new1)*

If the priority is "Very High" the current task has to be stopped as soon as possible and the ticket the MP is working on needs to be set to "Internal Disruption". The MP is then enabled to accept the new task and can sign onto the corresponding ticket.

The next step is to check which machine is affected. This information is provided by the PDA system and displayed on the smartphone. The MP then goes to the machine and performs the necessary tasks. After completion he closes the services ticket which is subsequently reported to the ERP system (Figure 4-14). Simultaneously the worker can report the repair completion at the PDA terminal and continue his work (Figure 4-15).

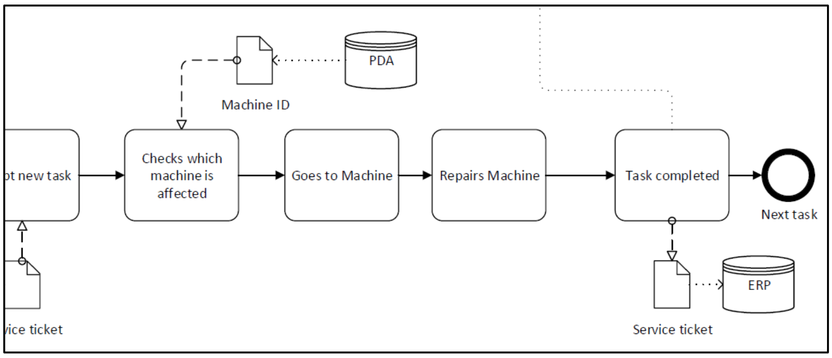



*Figure 4-14 Tasks performed by MP (new2)*

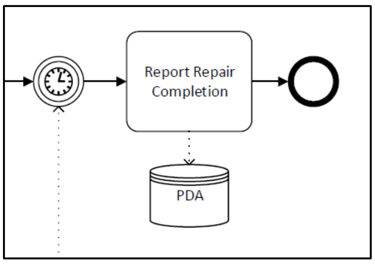



*Figure 4-15 Tasks performed by machine operator (new2)*

#### 4.5.1.5 Required Changes

To implement and use the system according to the just presented procedure several changes to the current system are required. Those changes are presented in the following section.

##### Downtime classes

At the production data acquisition system, the machine operator could previously choose between the following downtime options:

- Set up and cleaning: This is considered as planned downtime and was chosen e.g. between orders when tools needed to be changed as well as for the time needed for cleaning the machine after each shift.
- Service: This is also considered as planned downtime which was activated when service tasks were necessary. (Refilling the cooling liquid tank, re-oiling or other planned service tasks e.g. after a specific predetermined interval)
- Failure: This is considered as unplanned downtime. This option was chosen when e.g. the operator crashed into the part or the mounting device or any other unplanned failure occurred (e.g. increased spindle backlash, stuck feeding device, …)

The different downtimes have been activated by pushing a button which was already available at the PDA terminal and the time as well as the affected machine was then stored in the PDA system. This information is also required for the new process and can be used unchanged.

To provide the required additional information, it is necessary to have a more detailed view at the current *Failure* state. To be able to choose already at the PDA terminal which maintenance worker is required, three new subdividing fields have to be implemented below the already available *Failure* state level into the system. One where the machine operator is able to contact the electrician, one which informs the mechanic and a third one which calls for the need of both. This implementation is done by the company's IT department.

Besides the downtime classes also the priority levels have to be adapted to best fulfill the requirements and the necessary actions are described in the next section.

##### Priority levels

Currently the ticket system in the enterprise resource planning (ERP) system has four different priority levels to choose from:

- Very High
- High
- Normal
- Not classified

The problem occurring at using these three (four if *Not classified* is counted) levels is that no clear actions are defined for the specific priority. In order to optimize the process according to the intended changes these levels have to trigger the following specific actions:

- **Very high**: The current task has to be stopped as fast as possible and the requested person has to check the affected machine. If the maintenance worker is already assigned to a *"Very High"* classified tasks the production manager has to decide which of the tasks needs to be completed first and therefore reschedule the task list accordingly. The maintenance gets informed with the updated list and knows immediately which task to work on.
- **High**: The task the MP is currently working on can be finished and afterwards the task classified as *High* has to be the next to be taken care of. If there are several tasks with the same classification, the production manager is able to reschedule them according to the specific importance.
- **Normal**: Tasks classified as *Normal* should be executed in the order they occurred and they are sequenced in the list of tasks to do.
- **Not classified**: Tasks that are assigned with no specific classification are only of little importance and therefore can be completed when no other tasks are in the line.

#### 4.5.1.6 Advantages

One advantage of implementing this solution is that the machine operator no more needs to look for the production manager because he will be informed instantly after reporting the failure of the machine at the PDA terminal. This eliminates the need to personally contact the PM.

If the required changes regarding the priority levels are implemented, the need of the production manager to be capable of issuing directives to the MW disappears due to the clear declaration of the meaning of the different priority levels.

A further subdivision of the state *Failure* of a machine enables the operator to preselect the required MW and is used to assign the MW to the tasks. This automatization diminishes the need for human actions.

All these measures lead to a reduction of the reaction time as it can be seen in Figure 4-16. The actions causing the time periods t2, t3 and t4 are combined to one single tasks being the prioritization of the tasks by the PM (t6). The time period t1 can't be reduced because the worker will always require some time to report the failure at the PDA. The time period t5 is variable and is related to the current task the MW is currently working on. E.g. if the MW is currently repairing the crane under the roof of the production hall he won't interrupt this job and results in a longer time period t5. On the other hand, if the MW is waiting for his next tasks t5 can be reduced to a minimum.

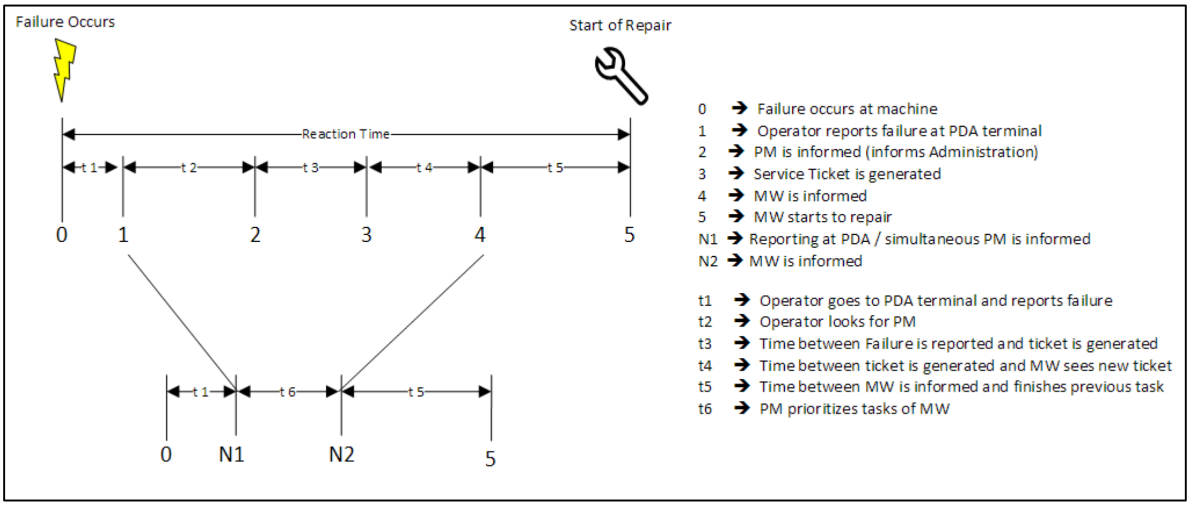



*Figure 4-16 Reaction time reduction*[242]

#### 4.5.1.7 Conclusion

As it can be seen in Figure 4-16 the reaction time can be reduced according to the new process installed. The timespan between the failure occurs and the machine operator reports the failure at the PDA terminal cannot be reduced as well as the time between the MW is informed and when he starts working on the machine. The latter can be explained because if the MW is currently working on a task he might not be able to stop this task right away and start the repair at the affected machine.

The time between the failure is reported at the PDA terminal and the PM is informed (t2) is now eliminated.

The time between the PM is informed and the MW is informed (t3 + t4) are reduced to a minimum and are resulting in t6, the time it takes to prioritize the tasks.

Due to this fact and the according analysis of the data sets provided by the company an estimated reduction of the reaction time of about 30% can be achieved. The actual reduction will only be determinable when the solution is finally implemented at the company.

## 4.6 Measure and Monitor / Continuously Improve Process

The last two phases of the optimization process being the measuring and monitoring as well as the continuous improvement has not yet been realized due to the limited time available for the use case. The company is currently waiting for the implementation of the system at their site which is done by the platform provider. Subsequently the smartphone application can be generated by the IT department. The implementation process is scheduled to be finished in July 2016 and then the measures to monitor the improvements will be developed and the actions for the continuous improvement process are determined.

[242] Own representation

## 4.7 Learnings of the Use Case

During this use case it was shown that the optimization of internal processes is often the first and most obvious measure when starting the implementation of I4.0. The explanation for this is that the increased use of digital technologies can result in a higher degree of automatization and therefore increase the efficiency of the respective processes. The implementation of smart mobile devices in combination with a software platform in the presented case additionally increased the transparency of the process for the persons involved. The necessary investment in such process optimization measures is often less than the introduction of new technologies would require. Thus achieved optimizations can easily be measured comparing the key figures before and after the implementation and therefore justifies the required investments. Implementations of technologies like those presented during chapter 2.7 imply more extensive changes in the processes and therefore require more effort and resources and ultimately results in higher costs.

The challenges that will arise after the solution is implemented concerning the acceptance of the technology by the MW. The real effort which has to be put into the programming of the interface might represent further challenges. Due to the fact that the solution is mainly based on minor software changes the costs have not been a challenge in this project. The challenge of cybersecurity was also not of great concerns because the solution is only affecting the internal network of the company having already high security standards.

Saleable solutions like the one implemented in the presented use case also enable companies to start with small adoptions which can then be unrolled to a more extensive use. This is shown in the use case in terms of the intended expansion of the solution to the previously identified tool management use case which will be attempted after the initial implementation affecting the maintenance process.

The use case also increased the awareness of the head of production for future developments regarding I4.0 and created a more optimistic perspective. They now plan to monitor the ongoing developments in this field in more detail and will highly probably implement additional measures in the future.

# 5 Summary

Industry 4.0 is one of the most ubiquitous terms when speaking about the future of the manufacturing industry today. Since this initiative has been introduced to the public in 2011 a myriad of articles, research papers and other publications dealing with the theoretical applications and visions of this initiative have been released.

Due to the fact that currently several similar initiatives are attracting attention the first section of this thesis deals with the clarification of those initiatives and the different terms. Then Industry 4.0 was considered from the standpoint of the historic developments of the manufacturing industry and its role considering the future trends. The ongoing demographic changes, the shorter product lifecycles as well as the increasing demand for more customizable and individual products are exemplary trends that can be observed today. Amongst others, these trends definitely show the necessity of an imminent paradigm shift in this industry segment.

To fully and sustainably exploit the so far untapped potentials accompanying the introduction of information and communication technologies (ICT) into the manufacturing environment, some basic underlying concepts have to be considered. So called cyber-physical-systems (CPS) being the elementary building blocks. Those systems are realized by adding an additional layer of functionalities deploying ICT to the various objects. Those object are consequently enabled to sense and control their superordinate object and can communicate with other CPS via the different networks. Those systems are capable to make decentralized local decisions but are always considering the overarching global requirements coming from upstream and / or downstream of the organisation representing the horizontal integration. To support the human decision making process all the IT systems of a company, from the shop floor up to the corporate management level, have to be integrated into one consistent solution providing real time data of the status of a company which is known as vertical integration. These concepts are all representing the theoretical approach.

In the next section of this work the most prominent technologies empowering Industry 4.0 applications in the real world were investigated. The selection of these technologies were done according to their appearance in the pertinent publications and their respective influence being able of changing the way the manufacturing industry is seen today. The most mature technology in this context is the additive manufacturing which is already today changing the aviation industry. On the other end of the maturity scale is the industrial internet of things (IIoT). The ubiquity of the therefore required CPS' lacks due to several reasons like the costs, the complexity of the topic, the requirements on data safety and security as well as the lack of necessary talent and the lack of clear business cases that justify the investments. Those reasons are not only challenging the implementation of the IIoT but can be seen as the main implementation hurdles in advancing Industry 4.0.

The findings of the literature review have subsequently been evaluated while conducting interviews with experts from different industry sectors. The most experienced company is from the automotive industry which provides production lines to OEMs. The large volume production in this industry requires highly sophisticated equipment. The willingness of the OEM to invest in up to date technologies for their production lines led to an atmosphere which allowed to push the technological limits. The result was a showcase project where almost all of the identified technologies and concepts have been implemented. This shows that under the right circumstanced Industry 4.0 can already be realized today. All the other companies conducted their I4.0 projects optimizing their internal processes in the production. This emphasizes the findings from the literature review in which these areas could have also been identified as the most promising ones for I4.0 today.

Finally, having gained theoretical and practical insights about the implementation process of I4.0, the experiences were put into practice. Therefore, a company willing to and interested in implementing I4.0 measures was selected. During workshops a use case had been identified which was subsequently realized by introducing smart mobile devices supporting the automatization of internal processes. This introduction led to a reduction of the reaction time, the time between a failure of a machine occurs and the maintenance worker is starting to work on it, estimated to reach 30%. The people involved in this process will be provided with smartphones enabling decentralized, context and needs based provision of information. The so achieved autonomy of the maintenance workers resulted in a reduction of a machine downtime by minimizing the non-productive organizational tasks and improving the flow of information.

The conclusions derived from this work are that the primary activities performed while implementing I4.0 are the optimization of the internal processes, linking different systems and increasing the degree of automatization. The main department where these measures are taken is the production department. Those optimizations are mainly implemented making changes and adoptions to the existing software systems subsequently affecting the production processes. The introduction of new technologies has only been witnessed in specific industry branches where additionally only the most beneficial technologies for the respective sector have been implemented to some extent.

# 6 Outlook

Industry 4.0 is still a very hot topic in the manufacturing industry and more and more companies are building up competencies in this field.

According to a study by bitkom, a digital association from Germany, conducted prior to the Hannover Messe in 2016, today already 65% are using or planning to use I4.0 at their company. 57% of these companies have dedicated up to five percent of their current budget for such initiatives and 15% plan to employ new people especially for I4.0[250]

The numerous studies and publications investigated in this thesis showed that the ambitions of the investigated industry sector to put the theoretical visions into practical use cases are very high. This will lead to major changes in the near future. It seems that now the time has come for the expected paradigm coming along with I4.0. Compared to previous similar initiatives aiming at the same objectives like *Digital Manufacturing* in the 70s, *Computer Integrated Manufacturing* (CIM) in the 80s and 90s and the *Digital Factory* in the beginning of 2000, followed by *Factory 2.0* in 2005 and *Smart Factory* around 2007, I4.0 might have the potential to finally entrench the awaited fourth industrial revolution.[251]

[250] Riemensperger, F. 21.04.2016
[251] Roser, C. 2015

# Appendix

## A1 – Extract of data received containing the ticket system recordings

(columns blackened due to privacy issues of the affected persons)

| TICKETID | Category | SUBJECT | NAME | STATUS | PRIO | Worker | Opened | by | Closed | Response Nr. | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.340.588 | Betriebsschlosser Maschinenpark | Fräsmaschine F18 | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 06.11.2015 07:05:50 | [redacted] | 06.11.2015 14:39:00 | 12054042 | F18_2007_Fräsm.Reckerm.Beta_V |
| 9.353.051 | Betriebselektriker Maschinenpark | F71 | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.08.2015 07:24:46 | [redacted] | 07.08.2015 09:13:00 | 12054045 | F71_2008_Bohrwerk_Union_KC110 |
| 3.019.565 | Betriebselektriker Maschinenpark | F72 - Kühlmitteldüse aussen | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.03.2015 13:20:59 | [redacted] | 07.31.2015 10:33:00 | 12054046 | F72_2008_Bohrwerk_Union_KC110 |
| 2.616.433 | Betriebselektriker Maschinenpark | HB03 | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.21.2015 12:51:49 | [redacted] | 08.13.2015 07:21:00 | 12054028 | Handwerkzeug Inst. |
| 5.647.635 | Betriebselektriker Maschinenpark | Flurförderfahrzeug T7. 07 | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 07.20.2015 08:47:16 | [redacted] | 09.03.2015 06:58:00 | 12051027 | Inst. Diesel- u. E-Stapler EVG |
| 8.900.750 | Betriebselektriker Maschinenpark | F19 Späneförderer kaputt | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.26.2015 12:07:28 | [redacted] | 06.26.2015 13:09:00 | | |
| 5.004.313 | Betriebselektriker Maschinenpark | Ticket für F84 | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 07.08.2015 06:40:07 | [redacted] | 01.13.2016 11:57:00 | 12054035 | BAZ F84 |
| 6.059.992 | Betriebselektriker Maschinenpark | F81-Schaltschrankklimagerät | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 07.08.2015 09:11:45 | [redacted] | 07.16.2015 12:21:00 | 12054047 | F81 Bohrwerk TOS (511604) |
| 6.337.832 | Betriebsschlosser Maschinenpark | F15 | [redacted] | Geschlossen | Normal | Soboth Werner | 07.28.2015 06:36:20 | [redacted] | 07.31.2015 10:21:00 | 12054041 | F15_2007_BAZ_Reckerm.RBZ1520 |
| 6.038.974 | Betriebsschlosser Maschinenpark | Dreipackenfutter steckt bei der Drehmaschine D52 | [redacted] | Geschlossen | Normal | Soboth Werner | 07.29.2015 07:15:12 | [redacted] | 07.31.2015 06:13:00 | 12054040 | Drehmaschine D52 |
| 7.147.110 | Betriebsschlosser Maschinenpark | EVG HB F71 "Hebel für Bedienpult" | [redacted] | Geschlossen | Normal | Soboth Werner | 07.01.2015 07:12:34 | [redacted] | 08.19.2015 10:05:00 | 12054045 | F71_2008_Bohrwerk_Union_KC110 |
| 6.975.003 | Nicht zugeordnet | F22 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.05.2015 06:22:41 | [redacted] | 06.05.2015 08:59:00 | 12054036 | BE. Zentrum F22 |
| 8.851.290 | Betriebsschlosser Maschinenpark | Werzeugwechsler F22 ohne Funktion DRINGEND | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.05.2015 06:54:36 | [redacted] | 06.05.2015 09:05:00 | 12054036 | BE. Zentrum F22 |
| 2.586.778 | Betriebselektriker Maschinenpark | f11 | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.05.2015 08:14:51 | [redacted] | 07.02.2015 08:35:00 | 12054033 | 5119051 BAZ Deckel Maho (F11) |
| 7.742.658 | Betriebselektriker Maschinenpark | Fräsmaschine F11 | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.10.2015 12:15:03 | [redacted] | 07.02.2015 12:48:00 | 12054033 | 5119051 BAZ Deckel Maho (F11) |
| 7.596.676 | Betriebselektriker Maschinenpark | F94 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.30.2015 07:03:23 | [redacted] | 06.30.2015 12:21:00 | 12054048 | F94_2007_Langfräsm.Soraluce |
| 1.991.251 | Betriebselektriker Maschinenpark | S052 - Brennschneidanlage | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.01.2015 12:06:27 | [redacted] | 07.02.2015 12:26:00 | 12054037 | Brennschneidmasch. S052 (ESAB) |
| 7.991.074 | Betriebsschlosser Maschinenpark | F11 RS-Ventil defekt | [redacted] | Geschlossen | Normal | Soboth Werner | 07.01.2015 12:51:13 | [redacted] | 07.02.2015 08:39:00 | 12054033 | 5119051 BAZ Deckel Maho (F11) |
| 9.415.234 | Betriebselektriker Maschinenpark | Batterietausch - F21 BE5119071 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 07.14.2015 10:45:48 | [redacted] | 07.14.2015 13:54:00 | 12054044 | F21_2007_BAZ_Reckerm.RBZ850 |
| 8.433.092 | Betriebselektriker Maschinenpark | F20 | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.26.2015 07:03:56 | [redacted] | 07.02.2015 14:49:00 | | |
| 8.646.182 | Betriebselektriker Maschinenpark | Defektes Anschlusskabel | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.01.2015 15:23:41 | [redacted] | 06.01.2015 15:25:00 | 12052933 | EVG HB Schweißerei Inst. Tech. |
| 2.064.947 | Betriebselektriker Maschinenpark | Flurförderfahrzeug T7.17 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 07.16.2015 07:03:04 | [redacted] | 08.04.2015 06:27:00 | | |
| 3.515.645 | Betriebsschlosser Maschinenpark | F84 dringend | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.08.2015 13:02:14 | [redacted] | 06.10.2015 07:17:00 | 12054035 | BAZ F84 |
| 5.377.591 | Betriebselektriker Maschinenpark | Lampentauch für F94 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.10.2015 08:56:13 | [redacted] | 06.11.2015 14:42:00 | 12054048 | F94_2007_Langfräsm.Soraluce |
| 5.344.708 | Betriebselektriker Maschinenpark | F20 X-Achse defekt | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.08.2015 13:30:09 | [redacted] | 07.09.2015 15:33:00 | 12054043 | F20_2007_BAZ_Reckerm.RBZ850 |
| 3.131.279 | Abteilungsleitung Haustechnik | Bildschirm Brennschneideanlage | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 06.10.2015 10:40:53 | [redacted] | 06.10.2015 14:44:00 | | |
| 5.217.466 | Betriebselektriker Maschinenpark | F84 defekt | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 06.24.2015 07:31:07 | [redacted] | 06.25.2015 13:12:00 | 12054035 | BAZ F84 |
| 1.973.883 | Nicht zugeordnet | S052 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.24.2015 08:42:05 | [redacted] | 06.24.2015 12:25:00 | 12054037 | Brennschneidmasch. S052 (ESAB) |
| 1.540.247 | Betriebsschlosser Maschinenpark | H71. Undichtheit der Hydraulik | [redacted] | Geschlossen | Normal | Soboth Werner | 06.24.2015 13:58:31 | [redacted] | 07.01.2015 12:48:00 | 12054050 | Keilnutziehmasch. H71 (Balzat) |
| 6.293.914 | Betriebselektriker Maschinenpark | Kranrep. | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.03.2015 07:19:46 | [redacted] | 07.06.2015 06:35:00 | 12051021 | Inst. Kran- Anlagen EVG-Werk |
| 9.952.959 | Betriebselektriker Maschinenpark | F81 Werkzeugwechsler | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 07.03.2015 07:20:58 | [redacted] | 07.03.2015 08:52:00 | | |
| 2.899.069 | Betriebselektriker Maschinenpark | Kran in der Schweisserei defekt | [redacted] | Geschlossen | Sehr Hoch | Wohlkinger Klaus | 07.03.2015 08:00:16 | [redacted] | 07.03.2015 11:46:00 | 12051021 | Inst. Kran- Anlagen EVG-Werk |
| 6.016.464 | Betriebsschlosser Maschinenpark | EVG_HB3_F72_Kühlmitteldüse_Programmierbar tauschen | [redacted] | Geschlossen | Normal | Soboth Werner | 07.27.2015 09:54:31 | [redacted] | 07.28.2015 12:03:00 | 12054046 | F72_2008_Bohrwerk_Union_KC110 |
| 9.438.282 | Betriebselektriker Maschinenpark | M1136 | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.16.2015 12:47:19 | [redacted] | 07.17.2015 09:57:00 | 12052933 | EVG HB Schweißerei Inst. Tech. |
| 6.479.636 | Betriebselektriker Maschinenpark | F89 | [redacted] | Geschlossen | Hoch | Wohlkinger Klaus | 06.08.2015 06:58:21 | [redacted] | 06.26.2015 09:51:00 | 12054052 | Langfräsm. F89 |
| 8.978.537 | Betriebselektriker Maschinenpark | F84 - Späneförderer | [redacted] | Geschlossen | Normal | Wohlkinger Klaus | 06.19.2015 12:43:38 | [redacted] | 06.22.2015 14:36:00 | 12054035 | BAZ F84 |
| 4.899.787 | Betriebsschlosser Maschinenpark | F15 Luftschlauch | [redacted] | Geschlossen | Hoch | Soboth Werner | 06.22.2015 08:26:06 | [redacted] | 06.25.2015 12:26:00 | 12054041 | F15_2007_BAZ_Reckerm.RBZ1520 |
| 4.632.997 | Betriebsschlosser Maschinenpark | EVG HB Maschine F18 "Z-Achse" | [redacted] | Geschlossen | Hoch | Soboth Werner | 06.30.2015 08:42:10 | [redacted] | 07.29.2015 11:36:00 | 12054042 | F18_2007_Fräsm.Reckerm.Beta_V |

## A2 – Summary of the Interview with Test Fuchs

The interview was conducted on the 23rd of March 2016 via telephone. The interview partner was Mr. Michael Schilling who is the head of production and project management at Test Fuchs. In the following, the summary of the interview is presented:

In the year 2012 the company was confronted with the problem of how to keep the machining department in house as the orders were increasing and the current infrastructure was not able to keep up with the growth Test-Fuchs was facing. Increasing the automation level was one option that enabled a higher machine utilization and thus enhancing the output. The challenge the production was facing was to be able to produce batch size one as well as small series in an economic way and therefore a very flexible production equipment was needed which lead to an investment of small amount of tens of a million euro.

The purchasing and installation of new milling machines with large tool magazines capable of holding 350 tools were only the first step of the journey towards increased production efficiency. The feeding of the machine was realized by the installation of a conventional industrial robot in collaboration with a storage system that is operated by a shuttle delivering the necessary mounting equipment. In terms of changing and adapting the hardware that’s all that has been done so far.

By installing new hardware equipment an update regarding the software was necessary to be able to keep up with the requirements the future was holding.

The goal regarding the software was to enable a consistent documentation and thus to create a digital reflection of the real world production process. As the 3D models were already available from the development and design department these files with the conventional formats should be handed over to the CAM department where the production process was planned in a further detailed level. To support these activities, the integration of the physical tools and the associated parameters gathered during the measurements into the CAM process was required. Ensuring the connection of the physical tool at the shop floor with the virtual tool in the CAM department enabled for example the recording of the specific processing times of the individual tools. Having this additional data also enables the possibility to predict if the tool in the magazine of the machine has sufficient processing time left or if it needs to be exchanged. This lead to an increase in process reliability, transparency and efficiency as well as a significant reduction in set up time and enabled the production of components and spare parts within 24 hour including the necessary aviation certificates.

By fulfilling the desired requirements in the machining department Test – Fuchs was able to concentrate on a new project. Besides the consistent documentation in the machining department another process novelty in the electric facilities department was realized. Here consistency should also be the resource to gain the desired increase in process efficiency. By combining the data which was already available from the design process of the electrical plan, combining it with the 3D CAD data from the development and construction department, and adding the information of the elements used in the real electrical cabinet facilitates a new level of consistency in the electric components documentation.

A further project is already in its starting gates. The plan is to use tablets in the assembly department to support the workers there with the instructions including the latest changes made by upstream departments. Currently this issue is discussed and prepared to be able to implement it soon.

Beside the function as head of production and project management Mr. Schilling is also the head of a consulting firm called MISC Consulting which is dealing with the topics of internationalization, project management as well as I4.0. In this context some additional questions were asked on his specific expertise regarding I4.0 implementations and the hurdles and obstacles coming along with it.

According to him the biggest problem regarding I4.0 is that this topic is discussed very often on a high level but the real life actions concerning implementation are missing. The general expectations are too high and thus fear is arising even towards small implementation measures.

Two areas to begin with the implementation of I4.0 were mentioned namely the logistic area and the energy management. The similarities between these two are that these fields do not include special know how and the core competencies are often located somewhere else in the production process. Therefore, these two field are the perfect ones to start the implementation of I4.0.

Another point was that it is essential to build up I4.0 related competencies in house and not just trying to get the respective know how by purchasing external expertises. As an example in the logistic area RFID equipped trucks were mentioned which should enable an identification of the carried goods when the truck is arriving at the site without the need of manually checking and scanning the loads after the truck stopped and opened the tailgate. This is one exemplary step to start with the implementation.

One hint to start the process of using I4.0 technologies is to begin with small measures and getting comfortable with their usage as well as being able to see the benefits accompanying those actions. Only then the next step is to roll out the measures to the whole company.

## A – 3 Summary of the Interview with Ginzinger Electronic Systems

The interview was conducted on the 30th of March 2016 via telephone. The interview partner was Mr. Herbert Ginzinger who is the CEO and founder of the company. In the following the summary of the interview is presented:

In the beginning of 2013 Ginzinger electronic Systems introduced a new ERP System. The reason for this were the increasing customer requirements which they were not able to manage anymore with the existing system as well as the accompanying necessary changes in the whole company.

Previously they had a classical system were the orders and the start of the production were planned at a specific date in the planning department. When the order was planned the required material order was triggered. After the material arrived it was controlled and commissioned to the specific order and then put to stock. Before it was again released to the manufacturing department it had to be checked out of the stock. In the worst case this led to the fact that already four people treated the material before the value adding process was even started. This was the main problem ahead and initiated the wish for change.

The approach to find a new ERP system that could cope with the advanced requirements and the capability to create a system with a more dynamic approach was to look at systems available on the market. Typically, a list of requirements was generated and then transformed into a list of specifications which was finally sent to all ERP system suppliers and normally the one that offers the best solution usually gets the bid. At this point, luckily, the CEO of the company Eagle Peak [252]approached Mr. Ginzinger and said they won't offer a system like that, but what they could offer is a one-day workshop in which they together reflect and think about all the processes in the company. The main question raised was if the existing system is still capable to handle the customers' requirements they were facing.

During the phase of rethinking the implemented processes according to their needs they soon generated new processes and sequences which differed strongly from the previously developed mind map generated for the initially planned conventional ERP system. Seeing that the necessary processes have to be completely changed to fit best to the requirements they decided to go on with this alternative process and therefore chose to go with the approach Eagle Peak was offering.

Having realized this approach, they now have up to the minute real time data. This enables them to check the inventory with a single mouse click, see the current WIP and the status of the different orders and where each order in the production system currently is located or how many scrap has been produced so far. To get the data making such statements

[252]Eagle Peak is a provider of web browser based, configurable ERP system that can completely be tailored to the customers' needs (Details see: www.eagle-peak.de)

possible the installed and so called *operating system* for the production is a mixture between conventional ERP and MES systems. With this system they are enabled to include the data from all process relevant machines.

They were able to change from serial number to a unique identification numbers of the individual products and could so ensure the track- and traceability of each product. This number is laser engraved onto the module and with this number the module can be processed all along the production sequence by itself. Each machine is equipped with a reader that identifies the product when it enters the machine and the operating system knows all the required and necessary steps to successfully process the part. The first step is that the module enters the fitting machine and in it the printed circuit board is equipped with the correct parts. When the part is leaving the machine the installed parts are then checked out of the stock and booked onto the boards unique number which can be seen as a shopping cart with the installed parts as the content. Additionally, the process parameters of each process step are also stored in the cart ensuring a full traceability. This traceability is especially needed for security relevant parts where repairs are not allowed and that needs to be guaranteed and verifiable. This connection of the parts installed and the unique number creates an interlacing needed for specific customers that need to be able to check the parts mounted on the components within four hours in case of an accident or safety relevant event. The customer is therefore enabled to access the operating system, check for the installed parts and to make sure which other products might be affected as well.

After each processing machine the parts is checked and in the case of a failure the module is brought off the line and can then be repaired. The part also digitally is checked out and set to a failure status. After the repair process the status is reset and therefore the module can again be integrated back into the process.

A problem resulting out of this unique serial number which is pursued until the delivery process is that the customer would receive as many serial numbers as parts ordered. For example, if a customer orders 1000 circuit boards he would also get 1000 unique serial numbers. To overcome this problem a container serial numbers was created. This container serial number includes all unique serial numbers so the customer only sees the container serial number on his deliver note. This process also helped the customer to lower the effort for the incoming delivery checks and Ginzinger electronic systems was able to ensure that all the components ordered also were delivered without the need of manually counting them when arriving. Earlier they sometimes had the problem of complaints because the customer said there were too little parts shipped. A control was more or less impossible due to the possibility of human errors in the packaging department until the new automated system was established which enabled a full control in every step.

The consistency of this tracing starts already at the supplier side of the parts which are installed on the circuit boards. The incoming delivery batches get a specific number and this number is then used when filling the “shopping cart”.

All this led to an increase in production efficiency, higher functionality due to thorough consideration of the processes. The resulting higher customer loyalty is still the biggest benefit generated by implementing such a system with the described features although the monetary impact of this is hard to determine. As it is usual with the implementation of ERP systems the targeted costs were exceeded in this case by the factor four. Mr. Ginzingers’ opinion is that there is also a monetary benefit compared to conventional systems but as already mentioned the biggest impact is the increase in customer loyalty and the so achieved closer collaboration with the customers.

## A – 4 Summary of the Interview with Fill

In November 2015 Fill announced that they have completed their biggest metal cutting project since the foundation of the company. The project is considered as a showcase project for I4.0. ZMT automotive GmbH, a large subcontractor in the automotive industry ordered a processing line which is capable of performing all the necessary processing steps on a crankcase after the casting process. During an interview on the 19th of April 2016 Mr. Alois Wiesinger from the product development department at Fill explained some of the details of this project.

The crankcases arrive at ZMT in the state of an untreated casting part. In this state a Data Matrix Code (DMC) is already lasered onto the parts by the automotive manufacturer, who is producing the castings. The castings are sent batch wise to ZMT in lattice boxes. The digital content (the data and information about the individual parts) of the box is previously sent to ZMT by the automotive manufacturer in an email or via other web technologies and is automatically stored at the internal database. After scanning the batch number on the box at the incoming goods department the content of it is determined and can be set to “received” in the database.

The first step of the processing is the heat treatment and the following hardness test. The results of this test is then written on the individual parts using the DMC. Subsequently is a visual testing station which has 15 cameras installed on a robot arm. At this station the dimensional accuracy is checked and the results are also stored on the part. The next step is a visual control and measurement task which is performed manually. To support the worker in his tasks a touch panel is installed where a front- and top-view is displayed which is overlaid with a grid and the worker can, when a failure occurs, assign it to the respective cell of the grid which is also stored using the DMC. After this control section the metal cutting processes start.

Several machines, some from Fill and some provided by other vendors are forming the processing line. Therefore, they use their self-developed machine workflow framework which enables them to merge all the different data sources of the machines as well as to manage the workflow of the individual parts deciding if a parts need to be excluded or not. Additionally, they have clients installed which enable them to check for the current state of a product via a web browser using the DMC of the part. Information like date received, dates and times of the different test as well as when the parts was processed can be recalled.

If a failure occurs at any of the stations and is detected by the in process quality control the part is excluded directly by having installed a decentralized decision making instance.

All this information is the passed on to the outgoing goods area. Here the parts are packed into boxes which again have a unique number. This number again contains the information about the individual parts in the specific box. This data is then sent to the automotive manufacturer in advance so he knows that these parts are already processed. When the parts are finally loaded onto the truck, the boxes are scanned using mobile devices and the customer again is informed that the parts are loaded onto the truck.

When the automotive manufacturer detects failures at the parts at his incoming goods department and this might affect the whole batch, he can immediately stop the processing line at ZMT. The affected parts are then excluded from the line and are declared as scrap. This bidirectional communication of the quality data results in less scrap produced. Another application of this two-way communication is that the automotive manufacturer has the possibility to automatically exclude parts from specific process steps so additional quality control activities can be performed that wouldn’t be possible to conduct after all processing steps would have been performed on the part.

One of the main specifications by the customer ZMT was that at this line it should be possible to track and trace the parts processed. During the project an increasing use of I4.0 technologies were suggested to ZMT and they were fond of the ideas which were then realized as described before.

The biggest obstacle for Fill while implementing I4.0 is the conservative mentality of the mechanical engineering sector regarding new technologies and therefore convince their customers of the benefits these technologies deliver. Another big issue was the lack of talent especially regarding the IT and ICT know how. This had to be developed internally over the last years. This led to two new employees who are specialists in these fields.

The use of other technologies which are not implemented so far are currently under investigation. Additive manufacturing for grippers are only one example for this and the printing of sand cores for the casting process in the automotive industry is also a very interesting field. Augmented reality applications have been tested in several projects, but those devices are still not sufficiently developed for the industrial use.

The processing centers they are selling as another product are for example equipped with RFID tags. The tool management as well as the measurement protocols of the tools are stored there. Another application in development is equipping the mounting device with RFID tags so the machine knows, if the mounting device is installed on the machine bed which product will be produced and therefore can load the appropriate CNC program.

Their overall strategy regarding I4.0 is monitoring the current developments to stay competitive if technologies tend towards industrialization. Due to the fact that they are very customer oriented, their projects are directly designed and engineer for the customers and therefore they are not at risk of producing off-market products. To stay updated with the ongoing advancements they are also part of some research projects.

## A – 5 Summary of the Interview with Kresta Industries

Since 2012 they are interested in I4.0 and have identified and evaluated the elements which are relevant for their industry segment. In 2014 a partnership with an external partner was formed who supports the implementation activities. The interview was conducted on the 11th of April 2016 via telephone. The interview partner was Philipp Kreuzer, who is the head of production at Ki.

The main idea and area of application of the concept of I4.0 for Ki was to increase the level of automatization of processes as well as a higher degree of industrialization. The first tasks were to determine how to can change the current production according to the new and constantly changing requirements. They started to evaluate the relevant processes in the organizational area of the company and put the automatization of the production at first aside.

The first results of this evaluation led to the conclusion, that also the up- and downstream processes would be affected right away. In this context this would be the project management, the design and engineering department as well as the marketing and sales department. The upcoming consequence was that all processes need to be interlinked and the information flow between the different departments needed to be improved which would lead to one consistent IT system on which each level and stage in the hierarchy of the organization could work on. For example, the sales personal should be able to work with digital assembly groups already in the acquisition phase to better visualize the possibilities and the appearance of the planned plant. In the assembly phase at the customers site, respectively the other end of the value creation phase, the workers should be able to document occurring problems during the assembly process to realize a continuous improvement process where the generated data is transferred back to the overarching IT system. In the end both ends of the value creation chain should benefit from the work which is done by the engineering and design department.

The current IT system is, as it is often with steadily growing companies, separated into different silos. The ERP system is constrained to the commercial applications and departments. A typical MES system is not yet installed, but the according data is generated manually with lists and text files so far.

The overall vision of this first step towards I4.0 in the context of implementing a consistent engineering system is a production operating system, where all the data generated and required for a specific project is stored in one overall data container and can be accessed and used by any department calling for the according information. Additionally, in the operative segment a system should be implemented to be able to constantly monitor the processes.

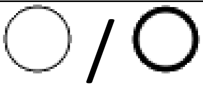
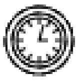
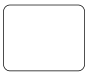
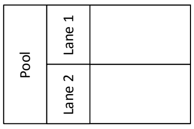
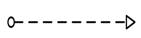
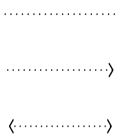
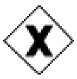
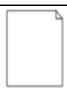
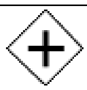
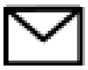
In the engineering and design department they implemented a new 3D - CAD system which is supported by a configurable and expandable product data management (PDM) system. With this tool a systematic approach to be able to reuse parts of previously engineered elements of a project for other or new projects is realized. The goal is a semi automatized design and engineering process. The main requirement for this CAD program in the context of consistent engineering regarding I4.0 was to be able to provide interfaces to many different other software tools like an ERP system, MES or others to be able to connect and interlink each with every other.

For the process of implementing I4.0, this first segment was separated into three sub processes. The first one is the organizational one which is completed to ~80%, the second, the introduction of the IT system, is completed to ~50% and the overarching system to realize the tracing and monitoring and the resulting continuous improvement process is completed to 20%. For the last sub process, the concept is already finished and currently the decision phase regarding which software tools to use is the next phase.

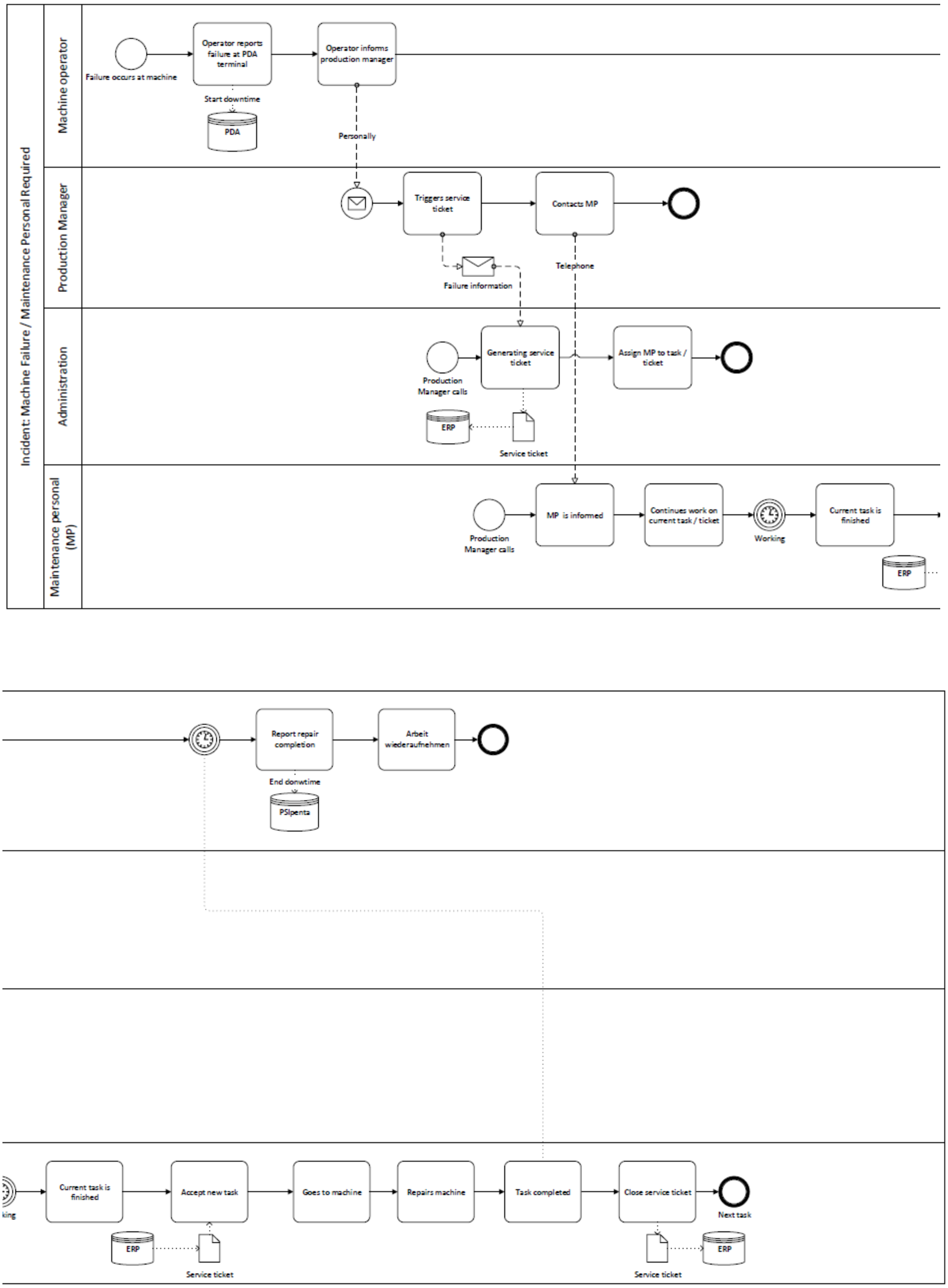
One solution realized to overcome the hurdles going along with such an implementation and change process was to call in external experts for the systematic support. Those experts have already been dealing with several other branches and therefore have extensive knowledge and experience beyond the respective industry sector. Another important topic for successful implementation is the change management regarding the employees and to convince them to be part of these changes.

Due to the fact that investments so far have been not very high, this was not an obstacle which had to be moved out of the way. The need for constantly being up to date with the industry standards to stay competitive and to follow the ongoing developments is much more important. The upcoming higher investments occurring when equipping the machines and bringing the developed concepts to factual ground are already considered.

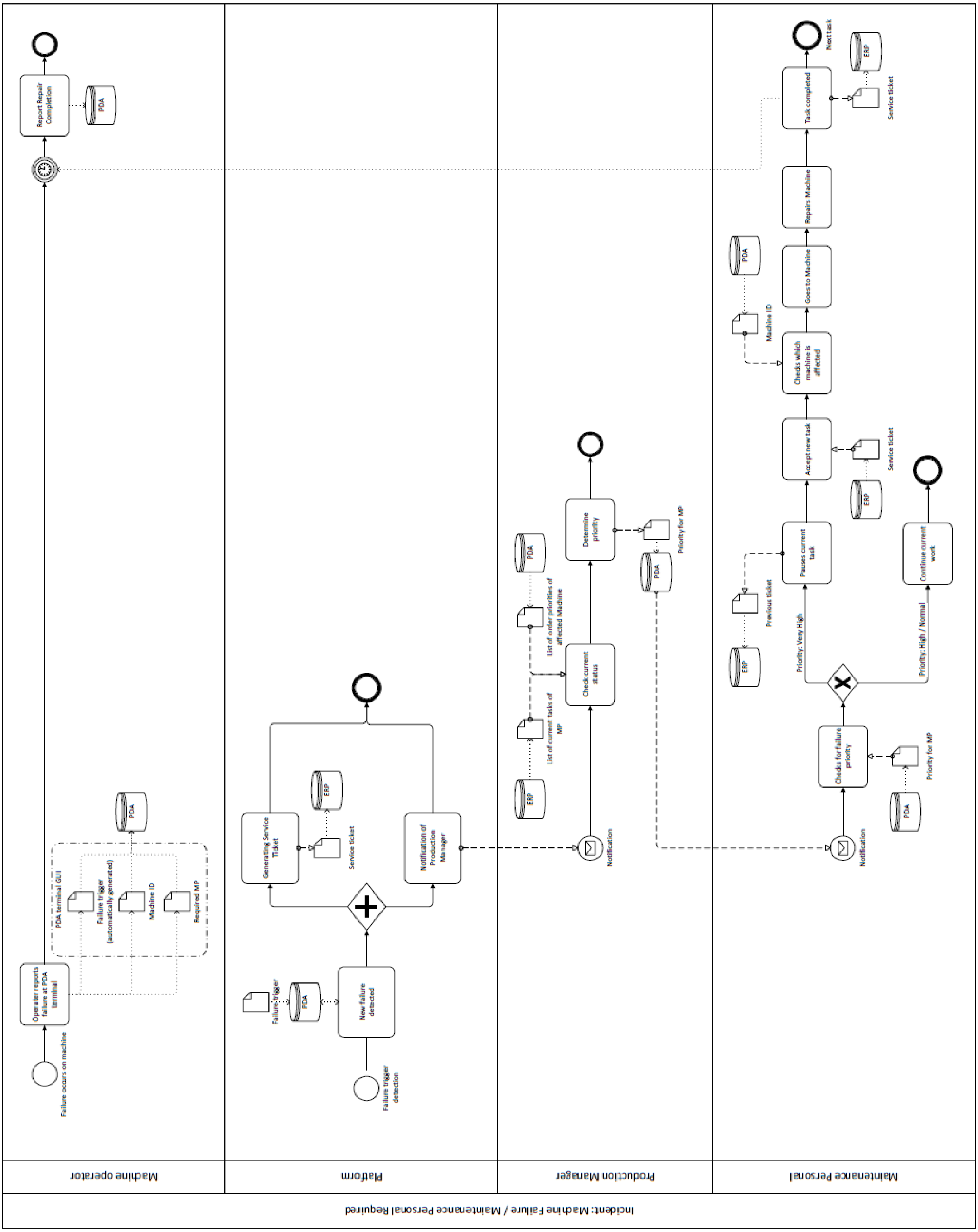
## A – 7 Symbols of the Business Process Modeling Notation (BPMN)

| Symbol | Description |
|---|---|
|  | Start / End Event:<br>The process starts / ends here without a specific condition |
|  | Start Message Event:<br>A process starts only if a message is received |
|  | Intermediate Timer Event:<br>The process waits until a specific amount of time passed |
|  | Task:<br>A task represents the activities to perform at this stage |
|  | Data store:<br>Is a place where the process can read or write data |
|  | Pools:<br>Represent the organizational unit or process. Pools can be subdivided with Lanes. Lanes represent respective responsibilities. |
|  | Sequence Flow:<br>Determines the sequence of the process |
|  | Message / Information Flow:<br>Indicate information that is passed beyond organizational (pool or lane) borders |
|  | Association (undirected, uni- or bi-directional):<br>Indicates exchange of information<br>Unidirectional: Start indicates writing – End reading<br>Bidirectional: Indicates changes of object during processing |
|  | Data based exclusive gateway:<br>Depending on the condition the sequence continues only at one path |
|  | Data object:<br>Represents objects that flows through the process |
|  | Parallel Gateway:<br>All subsequent tasks are processed simultaneously |
|  | Group:<br>Several objects that are somehow connected can be grouped. |
|  | Message:<br>Indicates the content of information |

# A – 8 Overview of Current Process



## A – 9 Overview of the Optimized Process



## A – 10 Investigated Publications to Identify Relevant Technologies

| Technology | | Sources 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Broadband | 8% | | | | | | | | | | | | | x |
| Speech recognition | 8% | | | | | | | | | | | | x | |
| Intelligent Materials | 8% | | | | | | | | | | | x | | |
| Exoskeletons | 8% | x | | | | | | | | | | | | |
| Energy efficiency & Resources | 8% | x | | | | | | | | | | | | |
| Automated Guided Vehicles | 15% | x | | | | x | | | | | | | | |
| Social Networks | 15% | | | | | | | | | | | x | x | |
| Simulation | 15% | | | x | | x | | | | | | | | |
| Plug & Produce | 31% | x | | | | x | x | | | | | | | x |
| Additive Manufacturing | 62% | | x | x | x | x | x | | | x | x | x | | |
| Human Machine Interface | 77% | x | | | x | x | | x | x | x | x | x | x | x |
| Industrial internet of things | 85% | x | | x | x | x | | x | x | x | x | x | x | x |
| Advanced Robotics | 69% | x | x | x | x | x | x | | | x | | x | | x |
| Mobile Solutions | 85% | x | x | | x | x | x | | x | x | x | x | x | x |
| Cloud | 85% | x | | x | x | x | x | x | x | x | x | x | | x |
| Big Data and Advanced Analytics | 100% | x | x | x | x | x | x | x | x | x | x | x | x | x |

| Source | Reference |
|---|---|
| 1 | Bauernhansl et. al. 2014 |
| 2 | Manyika J. et.al. 2012 |
| 3 | Rüßmann M. et.al. 2015 |
| 4 | Roth Armin 2016 |
| 5 | Bischoff Jürgen 2015 |
| 6 | Kagermann H. et.al. 2013 |
| 7 | Kaufmann Timothy 2015 |
| 8 | Tschöppe Sebastian et.al. 2015 |
| 9 | Bechthold J. et.al. 2015 |
| 10 | Usländer et.al. 2014 |
| 11 | Riedel, Heinen 2015 |
| 12 | Binezeisler 2014 |
| 13 | Bauer et.al. 2015 |

## A – 11 List of Abbreviations

| | |
|---|---|
| AM | Additive Manufacturing |
| AR | Augmented Reality |
| BPMN | Business Process Modeling Notation |
| BPR | Business Process Reengineering |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CNC | Computer numeric controlled |
| CRM | Customer Relationship management |
| DB | Database |
| FMC | Flexible Manufacturing cell |
| FMS | Flexible Manufacturing system |
| I4.0 | Industry 4.0 |
| ICT | Information and Communication Technology |
| IIoT | Industrial Internet of Things |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| MR | Mixed Reality |
| MW | Maintenance Worker |
| NC | Numerical Control |
| PDA | Production Data Acquisition |
| PM | Production Manager |
| MW | Maintenance Worker |
| PLC | Programmable Logic Controller |
| PLM | Product Lifecycle Management |
| PM | Production Manager |
| R&D | Research and Development |
| SCM | Supply Chain Management |
| SIT | Short Interval Technology |
| SME | Small and Medium Enterprises |
| TQM | Total Quality Management |
| VR | Virtual Reality |

# List of Literature

Abele, Eberhard; Grosch, Thomas; Schaupp, Eva [Smart Tool 2016], Smart Tool, Intelligentes sensorgestüztes Werkzeugmanagement, in: 3, 106. Jg. (2016)

Abele, Eberhard; Reinhart, Gunther [Zukunft der Produktion 2011], Zukunft der Produktion, Herausforderungen, Forschungsfelder, Chancen, s.l.: Carl Hanser Fachbuchverlag 2011

Adhani, Nur Intan; Rambli, Dayang Rohaya Awang [2012], A Survey of Mobile Augmented Reality Applications, Malaysia, Confernce Paper 2012

Adolph, Lars et al. [German Standardization Roadmap – Industry 4.0], German Standardization Roadmap – Industry 4.0

Al-Fuqaha, Ala et al. [Internet of Things 2015], Internet of Things, A Survey on Enabling Technologies, Protocols, and Applications, in: IEEE Commun. Surv. Tutorials, 17. Jg. (2015), S. 2347–2376

Anastassacos, Titos [2015], 3D printing will disrupt the spare parts market. The question is how, how soon and what to do about it, online im Internet unter http://serviceinindustry.com/2015/03/03/3d-printing-will-disrupt-the-spare-parts-markets/ [Stand 2016-04-06]

Ashton, Kevin [That 'internet of things' thing 2009], That 'internet of things' thing, in: RFiD Journal, 22. Jg. (2009), S. 97–114

Audi AG [2015], AU150039, online im Internet unter https://audimediacenter-a.akamaihd.net/system/production/media/4126/images/4ae67fff94ce1d81468759414bbb36c1d0fee84a/AU150039_full.jpg?1439258323 [Stand 2016-03-15]

Auschitzky, Eric; Hammer, Markus; Rajagopaul, Agesan [2014], How big data can improve manufacturing, online im Internet unter http://www.mckinsey.com/business-functions/operations/our-insights/how-big-data-can-improve-manufacturing [Stand 2016-05-11]

Azami Zaharim [Hrsg.] [Augmented Reality: Applications, Challenges and Future Trends 2014], Augmented Reality: Applications, Challenges and Future Trends, Proceedings of the 13th international conference on applied computer and applied computational science (ACACOS '14) : Kuala Lumpur, Malaysia, April 23-25 2014, [Greece]: WSEAS 2014

Azuma, R. et al. [Recent advances in augmented reality 2001], Recent advances in augmented reality, in: IEEE Computer Graphics and Applications, 21. Jg. (2001), S. 34–47

Bauer, Wilhelm; Bender, Manfred; Rally, Peter [Mitarbeiterorientierte Mensch-Roboter-Kollaboration 2016], Mitarbeiterorientierte Mensch-Roboter-Kollaboration, Partizipative Gestaltung von Mensch-Roboter-Kollaborationen führt zu akzeptierten Arbeitsplätzen, in: wt Werkstattstechnik online, 106. Jg. (2016), S. 100–105

Bauernhansl, Thomas; Hompel, Michael ten; Vogel-Heuser, Birgit [Hrsg.] [Industrie 4.0 in Produktion, Automatisierung und Logistik 2014], Industrie 4.0 in Produktion, Automatisierung und Logistik, Anwendung, Technologien, Migration, Wiesbaden: Springer Vieweg 2014

Baun, Christian et al. [Cloud Computing 2011], Cloud Computing, Web-basierte dynamische IT-Services, Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg 2011

Becker, Torsten [Prozesse in Produktion und Supply Chain optimieren 2008], Prozesse in Produktion und Supply Chain optimieren, 2. Aufl., o.O. 2008

BeyondTrust Software Inc. [2013], Simplifying the Challenges of Mobile Device Security, o.O. 2013, online im Internet unter https://www.beyondtrust.com/wp-content/uploads/Simplifying-the-Challenges-of-Mobile-Device-Security.pdf?1445039472 [Stand 2016-04-15]

Bi, Zhuming; Cochran, David [Big data analytics with applications 2014], Big data analytics with applications, in: Journal of Management Analytics, 1:4 (2014), S. 249–265

Bischoff, Jürgen [Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand 2015], Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand, Studie im Auftrag des Bundesministermiums für Wirtschaft und Energie (BMWi) (2015), o.O.

BITKOM e.V.; VDMA e.V.; ZVEI e.V. [2015], Umsetzungsstrategie Industrie 4.0, Ergebnisbericht der Plattform Industrie 4.0, o.O. 04/2015, online im Internet unter www.plattform-i40.de [Stand 2016-05-11]

Bosch Software Innovations [2015], Marktstudie Industrie 4.0: Bedarf und Nutzen vernetzter Softwarelösungen, hrsg. v. Bosch Software Innovations, o.O. 2015, online im Internet unter https://www.bosch-si.com/media/de/bosch_software_innovations/media_landingpages/market_survey_industry_4_0/20150928_industry4_0_market_study_en.pdf [Stand 2016-05-20]

Botthof, Alfons; Hartmann, Ernst Andreas [Hrsg.] [Zukunft der Arbeit in Industrie 4.0 2015], Zukunft der Arbeit in Industrie 4.0, [Autonomik Industrie 4.0], Berlin: Springer Vieweg 2015

Bouras, A. et al. [Product Lifecycle Management in the Era of Internet of Things: 12th IFIP WG 5.1 International Conference, PLM 2015, Doha, Qatar, October 19-21, 2015, Revised Selected Papers 2016], Product Lifecycle Management in the Era of Internet of Things: 12th IFIP WG 5.1 International Conference, PLM 2015, Doha, Qatar, October 19-21, 2015, Revised Selected Papers, o.O.: Springer International Publishing 2016

Bracht, Uwe; Geckler, Dieter; Wenzel, Sigrid [Digitale Fabrik 2011], Digitale Fabrik, Methoden und Praxisbeispiele, Berlin, New York: Springer 2011

Brecher, Christian; Lohse, Wolfram; Königs, Michael [Vernetzung von Arbeitsvorbereitung und Fertigung 2015], Vernetzung von Arbeitsvorbereitung und Fertigung, Ein Cloud-basierter Ansatz zur Erhöhung der Planungsqualität, in: ZWF, 110. Jg. (2015), S. 14–17

Brook, John Michael et al. [2016], The Treacherous 12, CSA's Cloud Computing Top Threats in 2016, hrsg. v. Cloud Security Alliance, o.O. 2016, online im Internet unter https://cloudsecurityalliance.org/download/the-treacherous-twelve-cloud-computing-top-threats-in-2016/ [Stand 2016-04-14]

Canon Inc. [2016], MREAL for Manufacturing, online im Internet unter https://www.usa.canon.com/internet/portal/us/home/explore/product-showcases/mixed-reality/mreal-for-manufacturing [Stand 2016-03-24]

Caudell, Thoma P.; Mizell, David W. [1992], Augmented reality: an application of heads-up display technology to manual manufacturing processes - System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on // Augmented reality: an application of heads-up display technology to manual manufacturing processes, online im Internet unter http://ieeexplore.ieee.org/ielx2/378/4717/00183317.pdf?tp=&arnumber=183317&isnumber=4717 [Stand 2016-03-17]

Croutear, Lance [2015], Industry 4.0 needs smart devices, online im Internet unter http://www.worksmanagement.co.uk/opinion/industry-4-0-needs-smart-devices/88295/ [Stand 2016-04-14]

Daqri International [2016], DAQRI Smart Helmet – DAQRI, online im Internet unter http://daqri.com/home/product/daqri-smart-helmet/ [Stand 2016-03-18]

Dietrich, David; Heller, Barry; Yang, BeiBei [Data science & big data analytics 2015], Data science & big data analytics, Discovering, analyzig, visualizing, and presenting data, Indianapolis, IN: Wiley 2015

Dorschel, Joachim [Praxishandbuch Big Data 2015], Praxishandbuch Big Data, Wiesbaden: Springer Fachmedien Wiesbaden 2015

Engomo GmbH [2015], Technologie - So funktioniert die Mobile Enterprise Lösung engomo, online im Internet unter https://www.engomo.com/de/produkt/technologie/ [Stand 2016-04-14]

Ensthaler, Jürgen et al. [2014], Statusreport Additive Fertigungsverfahren, o.O. September 2014, online im Internet unter https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/gpl_dateien/VDI_Statusreport_AM_2014_WEB.pdf [Stand 2016-03-30]

EVG Entwicklungs- und Verwertungs- Gesellschaft m.b.H. [2016], EVG, online im Internet unter www.evg.com

FactoryNet [2016], Neun Leitbetriebe Industrie 4.0, online im Internet unter https://factorynet.at/a/neun-leitbetriebe-industrie?af=Widget [Stand 2016-05-02]

Feigl, Kathrin [2015], New Human-Robot Cooperation in Audi's Production Processes, online im Internet unter https://www.audi-mediacenter.com/en/press-releases/new-human-robot-cooperation-in-audis-production-processes-1206/download [Stand 2016-05-10]

Fish, Eric [2011], Rapid Prototyping: How It's Done at GM, online im Internet unter http://www.adandp.media/articles/rapid-prototyping-how-its-done-at-gm [Stand 2016-04-06]

Fraunhofer IPT / ITL; KEX AG [2016], Additive Manufacturing, Potenziale und Risiken aus dem Blickwinkel der deutschen Werkzeugmaschinenhersteller, hrsg. v. VDW Verein Deutscher Werkzeugmaschinenfabriken, o.O. 23.02.2016, online im Internet unter http://www.metav.de/cipp/md_metav/lib/all/lob/return_download,ticket,g_u_e_s_t/bid,3060/no_mime_type,0/~/prae_kex_2016_02_23.pdf [Stand 2016-03-30]

Frenzel, Ulrich [2015], Deutscher Industrie "4.0 Index" 2015, online im Internet unter http://www.staufen.ag/fileadmin/hq/survey/STAUFEN._studie_deutscher_industrie_4_0_index_2015.pdf

Furht, Borivoje [Hrsg.] [Handbook of augmented reality 2011], Handbook of augmented reality, New York, NY: Springer 2011

Gao, Wei et al. [The status, challenges, and future of additive manufacturing in engineering 2015], The status, challenges, and future of additive manufacturing in engineering, in: Computer-Aided Design, 69. Jg. (2015), S. 65–89

Gartner Inc. [2015], Hype Cycle Research Methodology, online im Internet unter http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp [Stand 2016-05-22]

Gartner Inc. [2016], Gartner's 2015 Hype Cycle for Emerging Technologies, online im Internet unter http://www.gartner.com/newsroom/id/3114217 [Stand 2016-05-20]

Gebhardt, Andreas [3D-Drucken 2014], 3D-Drucken, Grundlagen und Anwendungen des Additive Manufacturing (AM), München: Hanser 2014

Geisberger, Eva et al. [2011], Cyber-Physical Systems, Driving force for innovation in mobility, health, energy and production, o.O. 2011, online im Internet unter http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Stellungnahmen/acatech_POSITION_CPS_Englisch_WEB.pdf [Stand 2016-04-08]

Geissbauer, Reinhard et al. [2014], Opportunities and challenges of the industrial internet, o.O. 2014 [Stand 2016-04-01]

Glass Almanac [2015], The History of Google Glass - Glass Almanac, online im Internet unter http://glassalmanac.com/history-google-glass/ [Stand 2016-03-17]

Graziani, Rick [IPv6 fundamentals 2012], IPv6 fundamentals, A straightforward approach to understanding IPv6, Indianapolis, Ind.: Cisco Press 2012

Haase, Tina et al., The Didactical Design of Virtual Reality Based Learning Environments for Maintenance Technicians, in: Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality, S. 27–38

Helmrich, Klaus [On the Way to Industrie 4.0 – The Digital Enterprise 2015], On the Way to Industrie 4.0 – The Digital Enterprise (2015)

Hermanns, Harry [Hrsg.] [Qualitative Forschung : ein Handbuch 2010], Qualitative Forschung : ein Handbuch, Reinbek bei Hamburg: Rowohlt-Taschenbuch-Verl. 2010

Heß, Peter; Wagner, Maximilian [Mensch-Roboter-Kollaboration in der Fertigung der Zukunft 2015], Mensch-Roboter-Kollaboration in der Fertigung der Zukunft, in: ZWF, 110. Jg. (2015), S. 755–757

Holdowsky, Jonathan et al. [2015], Inside the Internet of Things (IoT), online im Internet unter http://d27n205l7rookf.cloudfront.net/wp-content/uploads/2015/08/DUP_1102_InsideTheInternetOfThings.pdf [Stand 2016-04-08]

Howard, Chris et al. [2012], Hybrid IT: How Internal and External Cloud Services Are Transforming IT, online im Internet unter https://www.gartner.com/doc/1918214/hybrid-it-internal-external-cloud [Stand 2016-04-08]

Huang, Runze et al. [Energy and emissions saving potential of additive manufacturing 24.04.2015], Energy and emissions saving potential of additive manufacturing, The case of lightweight aircraft components, in: Journal of Cleaner Production (24.04.2015)

IBM Corporation [2016], IBM - What is cloud computing?, online im Internet unter https://www.ibm.com/cloud-computing/what-is-cloud-computing [Stand 2016-04-08]

IDC - Analyze the Future [2015], Industrie 4.0 in Deutschland 2015, online im Internet unter http://www.idc-central.de/files/infografik_industrie4.0_2015/IDC_Infografik_Industrie_40_DE_2015.pdf [Stand 2016-04-16]

ISO Standardization [2016], ISO/IEC 19510:2013 - Information technology -- Object Management Group Business Process Model and Notation, online im Internet unter http://www.iso.org/iso/catalogue_detail.htm?csnumber=62652 [Stand 2016-05-21]

Janardanan, Roshan [2013], Mobilit in Manufacturing: Technology and Innovation Lead the Way, online im Internet unter http://i.dell.com/sites/doccontent/business/solutions/whitepapers/en/Documents/mobility-manufacturing-technology-innovation-lead-the-way.pdf [Stand 2016-04-15]

Kagermann, Henning et al. [Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 2013], Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 (2013)

Kagermann, Henning; Lukas, Wolf Dieter [2011], Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, online im Internet unter http://www.ingenieur.de/Themen/Produktion/Industrie-40-Mit-Internet-Dinge-Weg-4-industriellen-Revolution [Stand 2016-04-01]

Kagermann, Henning; Lukas, Wolf-Dieter; Wahlster, Wolfgang [Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution 2011], Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, in: VDI nachrichten, 13. Jg. (2011), S. 2

Kagermann, Henning; Wahlster, Wolfgang; Helbig, Johannes [Recommendations for implementing the strategic initiative INDUSTRIE 4.0 2013], Recommendations for implementing the strategic initiative INDUSTRIE 4.0 (2013)

Kaisler, Stephen et al. [Hrsg.] [Big Data: Issues and Challenges Moving Forward 2013], Big Data: Issues and Challenges Moving Forward, o.O. 2013

Käppler, Wolf D. et al. [Smart Safety Management mit Ariadne SMS 2014], Smart Safety Management mit Ariadne SMS, o.O.: Springer-Verlag 2014

Katie Mohr [2016], 2016 Predictions: Augmented Reality Ready To Tackle Industrial Challenges, online im Internet unter http://www.manufacturing.net/blog/2016/01/2016-predictions-augmented-reality-ready-tackle-industrial-challenges [Stand 2016-03-18]

Kellner, Tomas [2014], World's First Plant to Print Jet Engine Nozzles in Mass Production - GE Reports, online im Internet unter http://www.gereports.com/post/91763815095/worlds-first-plant-to-print-jet-engine-nozzles-in/ [Stand 2016-04-06]

Kellner, Tomas [2015], The FAA Cleared the First 3D Printed Part to Fly in a Commercial Jet Engine from GE - GE Reports, online im Internet unter http://www.gereports.com/post/116402870270/the-faa-cleared-the-first-3d-printed-part-to-fly/ [Stand 2016-04-06]

Kinkel, Steffen [Erfolgsfaktor Standortplanung 2009], Erfolgsfaktor Standortplanung, In- und ausländische Standorte richtig bewerten, 2. Aufl., s.l.: Springer-Verlag 2009

Knapp AG [2016], KiSoft WebEye, online im Internet unter https://www.knapp.com/cms/cms.php?pageName=glossary&iD=37 [Stand 2016-05-02]

KuKa AG, LBR Iiwa, online im Internet unter http://www.kuka-robotics.com/NR/exeres/C4243A0D-B3E3-4BB7-9513-12121B03BE42 [Stand 2016-03-15]

Laney, Doug [2001], 3D Data Management: Controlling Data Volume, Velocity, and Variety, online im Internet unter http://blogs.gartner.com/doug-laney/files/2012/01/ad949-3D-Data-Management-Controlling-Data-Volume-Velocity-and-Variety.pdf [Stand 2016-05-01]

Lee, Jay; Bagheri, Behrad; Kao, Hung-an [A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems 2015], A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, in: Manufacturing Letters, 3. Jg. (2015), S. 18–23

Lee, Jay et al. [Industrial Big Data Analytics and Cyber-physical Systems for Future Maintenance & Service Innovation 2015], Industrial Big Data Analytics and Cyber-physical Systems for Future Maintenance & Service Innovation, in: Procedia CIRP, 38. Jg. (2015), S. 3–7

Lee, Jay et al. [Recent advances and trends in predictive manufacturing systems in big data environment 2013], Recent advances and trends in predictive manufacturing systems in big data environment, in: Manufacturing Letters, 1. Jg. (2013), S. 38–41

Li, Jingran et al. [Big Data in product lifecycle management 2015], Big Data in product lifecycle management, in: The International Journal of Advanced Manufacturing Technology, 81. Jg. (2015), S. 667–684

Lichtblau, Karl et al. [2015], Industrie 4.0 Readiness, Aachen, Köln 2015, online im Internet unter http://www.impuls-stiftung.de/documents/3581372/4875835/Industrie%204.0%20Readniness%20IMPULS%20Studie%20Oktober%202015.pdf/447a6187-9759-4f25-b186-b0f5eac69974;jsessionid=299CB673659621A12F6129DC279800F4 [Stand 2016-05-20]

Lueth, Knud Lasse [2014], Why it is called Internet of Things: Definition, history, disambiguation, online im Internet unter http://iot-analytics.com/internet-of-things-definition/ [Stand 2016-04-01]

Madison, Dan [Process mapping, process improvement, and process management 2005], Process mapping, process improvement, and process management, A practical guide for enhancing work and information flow, Chico Calif.: Paton Press 2005

Manyika, James et al. [2011], Big data: The next frontier for innovation, competition, and productivity, online im Internet unter http://www.mckinsey.com/business-functions/business-technology/our-insights/big-data-the-next-frontier-for-innovation [Stand 2016-05-11]

Manyika, James et al. [The Internet of Things: Mapping the Value Beyond the Hype 2015], The Internet of Things: Mapping the Value Beyond the Hype, in: McKinsey Global Institue (2015)

Mell, P. M.; Grance, T. [The NIST definition of cloud computing 2011], The NIST definition of cloud computing (2011), Gaithersburg, MD: National Institute of Standards and Technology

Mellor, Stephen; Hao, Liang; Zhang, David [Additive manufacturing 2014], Additive manufacturing, A framework for implementation, in: International Journal of Production Economics, 149. Jg. (2014), S. 194–201

Meseke, Bodo [2015], Datenklau: neue Herausforderungen für deutsche Unternehmen, online im Internet unter http://www.ey.com/Publication/vwLUAssets/EY-Datenklau-2015-Praesentation-final/$FILE/EY-Datenklau-2015-Praesentation-final.pdf [Stand 2016-05-19]

Meyer, Lutz; Reker, Jürgen [2016], Industrie 4.0 im Mittelstand, online im Internet unter https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Mittelstand/industrie-4-0-mittelstand-komplett-safe.pdf [Stand 2016-05-11]

Milgram, Paul; Kishino, Fumio [A Taxonomy of Mixed Reality Visual Displays], A Taxonomy of Mixed Reality Visual Displays, 77. Jg.

Netsuite [2016], How Cloud ERP Compares to On-premise ERP, online im Internet unter http://www.netsuite.com/portal/resource/articles/on-premise-cloud-erp.shtml [Stand 2016-04-13]

Panorama Consulting Solutions [2015 ERP Report 2015], 2015 ERP Report (2015)

Panorama Consulting Solutions [2016], 2016 REPORT ON ERP SYSTEMS AND ENTERPRISE SOFTWARE, online im Internet unter http://panorama-consulting.com/resource-center/2016-erp-report/ [Stand 2016-04-13]

Pearson, Mark et al. [2014], Big data analytics in supply chain: Hype or here to stay, hrsg. v. accenture, o.O. 2014, online im Internet unter https://www.accenture.com/t20150523T024812__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_2/Accenture-Global-Operations-Megatrends-Study-Big-Data-Analytics.pdf [Stand 2016-03-16]

Pfeiffer, Kai [2016], ROB@WORK 3, online im Internet unter http://www.ipa.fraunhofer.de/fileadmin/user_upload/Kompetenzen/Roboter-_und_Assistenzsysteme/Industrielle_und_gewerbliche_Servicerobotik/Produktblatt_rob%40work_3.pdf [Stand 2016-05-10]

Pielot, M.; Diefenbach, S.; Henze, N. [Mensch und Computer 2015 – Tagungsband 2015], Mensch und Computer 2015 – Tagungsband, o.O.: De Gruyter 2015

Plaas, Christoph [Industrie 4.0 als Chance begreifen 2015], Industrie 4.0 als Chance begreifen, o.O. 2015

Raihana, G. Fathima Hasseen [Cloud ERP - A solution Model 2012], Cloud ERP - A solution Model, 2. Jg. (2012)

Reinhart, Gunther; Engelhardt, Philipp; Genc, Emin [Digitale Fabrik, Automatisierung, Informationsmanagement RFID-basierte Steuerung von Wertschöpfungsketten 2013], Digitale Fabrik, Automatisierung, Informationsmanagement RFID-basierte Steuerung von Wertschöpfungsketten, in: 2, 103. Jg. (2013)

Riemensperger, Frank [Industrie 4.0 – wie Sensoren, Big Data und 3D-Druck die Produktion und die Arbeit in der Fabrik verändern], Industrie 4.0 – wie Sensoren, Big Data und 3D-Druck die Produktion und die Arbeit in der Fabrik verändern, Berlin 21.04.2016

Ripal, Vyas [2014], Why Are Mobility Solutions Challenging for the Manufacturing Industry?, online im Internet unter http://insights.wired.com/profiles/blogs/are-mobility-solutions-challenging-for-manufacturing-industry#axzz45ssl47P7 [Stand 2016-04-15]

Roberts, Mike [2014], 9 Ways Mobility Is Impacting the Manufacturing Environment Today, online im Internet unter http://blog.lnsresearch.com/blog/bid/203360/9-ways-mobility-is-impacting-the-manufacturing-environment-today [Stand 2016-04-15]

Roser, Christoph [2015], A critical look on Industry 4.0 | AllAboutLean.com, online im Internet unter http://www.allaboutlean.com/industry-4-0/ [Stand 2016-05-06]

Roth, Armin [Hrsg.] [Einführung und Umsetzung von Industrie 4.0 2016], Einführung und Umsetzung von Industrie 4.0, Grundlagen, Vorgehensmodell und Use Cases aus der Praxis, Berlin, Heidelberg: Springer Berlin Heidelberg 2016

Rouse, Margaret [2010], What is Software as a Service (SaaS), online im Internet unter http://searchcloudcomputing.techtarget.com/definition/Software-as-a-Service [Stand 2016-04-12]

Rouse, Margaret [2015], What is Platform as a Service (PaaS)?, online im Internet unter http://searchcloudcomputing.techtarget.com/definition/Platform-as-a-Service-PaaS [Stand 2016-04-12]

Rouse, Margaret [2016], What is self-service analytics? - Definition from WhatIs.com, online im Internet unter http://searchbusinessanalytics.techtarget.com/definition/self-service-analytics [Stand 2016-05-22]

Sander, Alsion; Wolfgang, Mel [2014], The Rise of Robotics, online im Internet unter https://www.bcgperspectives.com/Images/The_Rise_of_Robotics_Aug_2014_tcm80-168791.pdf [Stand 2016-05-18]

Schaeffer, Chuck [2013], How to Use Big Data in Manufacturing, online im Internet unter http://www.crmsearch.com/manufacturing-bigdata.php [Stand 2016-03-17]

Schmid, Manfred [Additive Fertigung mit Selektivem Lasersintern (SLS) 2015], Additive Fertigung mit Selektivem Lasersintern (SLS), Prozess- und Werkstoffüberblick, Wiesbaden: Springer Vieweg 2015

Scholz-Reiter, Bernd et al. [Möglichkeiten und Herausforderungen der RFID Integration in logistischen Prozessen bei kleinen und mittelständischen Unternehmen 2006], Möglichkeiten und Herausforderungen der RFID Integration in logistischen Prozessen bei kleinen und mittelständischen Unternehmen (2006)

Schröder, Christian [2016], Herausforderungen von Industrie 4.0 für den Mittelstand, online im Internet unter http://library.fes.de/pdf-files/wiso/12277.pdf [Stand 2016-05-19]

Schuh, Günther et al. [Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0 2014], Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0, in: Procedia CIRP, 19. Jg. (2014), S. 51–56

Schulz, Matthias; Göpfert, Ingrid [Hrsg.] [Automobillogistik 2013], Automobillogistik, Stand und Zukunftstrends, 2. Aufl., Wiesbaden: Springer Gabler 2013

Schwab, Adolf J. [Managementwissen für Ingenieure 2014], Managementwissen für Ingenieure, Wie funktionieren Unternehmen?, 5. Aufl., Berlin: Springer Vieweg 2014

Sendler, Ulrich [Hrsg.] [Industrie 4.0 2013], Industrie 4.0, Beherrschung der industriellen Komplexität mit SysLM, Berlin, Heidelberg, s.l.: Springer Berlin Heidelberg 2013

Sheng, Quan Z.; Li, Xue; Zeadally, Sherali [Enabling Next-Generation RFID Applications 2008], Enabling Next-Generation RFID Applications, Solutions and Challenges, in: Computer, 41. Jg. (2008), S. 21–28

Sirkin, Harold L.; Zinser, Michael; Rose, Justin [2015], Industries and Economies Leading the Robotics Revolution, online im Internet unter https://www.bcgperspectives.com/content/articles/lean-manufacturing-innovation-industries-economies-leading-robotics-revolution/ [Stand 2016-04-17]

Sower, Victor et al. [2012], U.S. Manufacturers Report Greater RFID Usage - RFID Journal, online im Internet unter http://www.rfidjournal.com/articles/view?9589/3#back-from-modal [Stand 2016-05-18]

Statista [Industrieroboter Weltweit - Statista - Dossier 2015], Industrieroboter Weltweit - Statista - Dossier (2015)

Stier, Kerstin [2015], Mobile Produktionssteuerung | ERP, online im Internet unter http://www.it-zoom.de/it-mittelstand/e/mobile-produktionssteuerung-11777/ [Stand 2016-04-14]

Stratasys [2013], Reducing Fixturing Costs with 3D Printing | Stratasys, online im Internet unter http://www.stratasys.com/resources/case-studies/consumer-goods/oreck [Stand 2016-05-10]

Stratasys [Jigs and Fixtures 2014], Jigs and Fixtures (2014)

Swedberg, Claire [German Manufacturer Links Workers to Parts and Stations Via RFID, Bluetooth 26.08.2015], German Manufacturer Links Workers to Parts and Stations Via RFID, Bluetooth (26.08.2015)

Tamm, Gerrit; Tribowski, Christoph [Hrsg.] [RFID 2010], RFID, Heidelberg: Springer 2010

Tate, Paul [2015], Hannover Day 2: Challenges to Industry 4.0, online im Internet unter http://www.gilcommunity.com/blog/hannover-day-2-challenges-industry-40/ [Stand 2016-05-19]

TCS [2015], The Internet of Thigns: TCS Global Trend Strudy 2015 - A Manufacturing Industry Perspective, o.O. 2015, online im Internet unter http://www.tcs.com/SiteCollectionDocuments/White-Papers/Internet-of-Things-Manufacturing-Industry-Perspective-1115-1.pdf [Stand 2016-03-23]

The Boston Consulting Group [2016], The Shifting Economics of Global Manufacturing, How a Takeoff in Advanced Robotics Will Power the Next Productivity Surge, online im Internet unter http://de.slideshare.net/TheBostonConsultingGroup/robotics-in-manufacturing [Stand 2016-04-13]

Veit, Daniel et al. [Business Models – An Information Systems Research Agenda], Business Models – An Information Systems Research Agenda, in: Business & Information Systems Engineering

[Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality], Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality, o.O.

Wee, Dominik et al. [Industry 4.0 2015], Industry 4.0, How to navigate digitization of the manufacturing sector, in: McKinsey Digital (2015)

Wee, Dominik et al. [Industry 4.0 after the initial hype 2016], Industry 4.0 after the initial hype, Where manufacturers are finding value and how they can best caputre it, in: McKinsey Digital (2016)

Weghofer, Franz [2015], Industrie 4.0 Anforderungen an die Digitale Fabrik, o.O. 2015, online im Internet unter http://docplayer.org/4170541-Industrie-4-0-anforderungen-an-die-digitale-fabrik.html [Stand 2016-04-14]

www.barcodesinc.com, RFID Buying Guide - BarcodesInc, online im Internet unter https://www.barcodesinc.com/info/buying-guides/rfid/ [Stand 2016-05-06]

www.mittelbayerische.de, Kollege Roboter in der Industrie 4.0, online im Internet unter http://www.mittelbayerische.de/wirtschaft-nachrichten/kollege-roboter-in-der-industrie-40-21840-art959343.html [Stand 2016-03-15]