Master Thesis

Technologies for SMEs in Industry 4.0

submitted to the

University of Leoben

at the

Chair of Industrial Logistics

Author:
Liangliang Shang
m00522659

Thesis Advisor:
Univ.-Prof. Dr. Helmut Zsifkovits

Leoben, 31.01.2019

Affidavit

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

Liangliang Shang

Leoben, 31.01.2019

Acknowledgement

I would like to extend thanks to the people, who so generously contributed to the work presented in this thesis.
First I would like to express my special appreciation and thanks to my advisor Univ.-Prof. Dr. Helmut Zsifkovits for his constant support during the compilation of this master thesis.
A special thanks to my parents. They were always supporting me and encouraging me with their best wishes. At the end I would like express appreciation to my beloved wife Aiping Zhang. She was always there cheering me up and stood by me through the good times and bad.

Kurzfassung

Industrie 4.0 wird als vierte industrielle Revolution eingeführt und ist ein Sammelbegriff für Technologien und Konzepte der Wertschöpfungskettenorganisation. Dies führt zu einer verbesserten Produktivität und Effizienz, einer besseren Flexibilität und Agilität und einer höheren Rentabilität.

Kleine und mittlere Unternehmen sind das Rückgrat der Volkswirtschaften auf der ganzen Welt. Sie sind ein dynamischer und wachsender Sektor in den meisten Volkswirtschaften der Welt.

Um wettbewerbsfähig zu bleiben, müssen kleine und mittlere Unternehmen den Produktentwicklungs- und Produktionsprozess ständig verbessern. Die Technologien von Industrie 4.0 können dabei helfen, diese Probleme zu lösen. Eine große Herausforderung in der Zukunft liegt daher im Transfer des Industrie 4.0 Technologien in kleine und mittlere Unternehmen.

Diese Masterarbeit konzentriert sich zunächst auf eine Literaturrecherche verschiedener Technologien in Industrie 4.0. Dann werden die Unterschiede zwischen kleinen und mittleren Unternehmen und großen Unternehmen aufgezeigt. Danach werden die Vor- und Nachteile kleiner und mittlerer Unternehmen herausgearbeitet. Das Kernthema dieser Arbeit ist es herauszufinden, welche der Technologien in Industrie 4.0 für kleine und mittlere Unternehmen geeignet sind, die anhand ihrer Merkmale und ihrer Situation mithilfe von ermittelten Kriterien bewertet werden.

Abstract

Industry 4.0 is introduced as fourth industrial revolution and is a collective term for technologies and concepts of the value chain organization. This leads to better flexibility and agility, improved productivity and efficiency, and increased profitability. Small and medium-sized enterprises are the backbone of the economies in the world. They are a dynamic and growing sector in most economies around the world.

To stay competitive, small and medium-sized enterprises must constantly improve the product development and production processes. The technologies within Industry 4.0 can support small and medium-sized enterprises to solve these issues. Therefore a great challenge in the future lies in the transfer of the Industry 4.0 technologies to small and medium-sized enterprises.

At first this master thesis focuses on a literature review of various technologies in Industry 4.0. Then the differences between small and medium-sized enterprises and large enterprises are shown. Afterwards the advantages and disadvantages of small and medium-sized enterprises are elaborated. The core issue of this thesis is to find out which of the technologies in Industry 4.0 are suitable for small and medium-sized enterprises which are evaluated by their attributes and situation with the help of identified criteria.

Table of contents

Affidavit I

Acknowledgement II

Kurzfassung III

Abstract IV

Table of contents V

List of figures VII

List of tables VIII

1 Introduction 1

1.1 Initial situation 1

1.2 Structure of the thesis 2

2 Industry 4.0 3

2.1 Definition of Industry 4.0 3

2.2 Technologies for Industry 4.0 8

2.2.1 Data analysis 8

2.2.1.1 Big data and analytics 8

2.2.1.2 Cloud computing 10

2.2.2 Identification 13

2.2.2.1 Radio frequency Identification (RFID) 13

2.2.2.2 Sensors and actuators 16

2.2.2.3 QR code 18

2.2.3 Workplace 19

2.2.3.1 Machine-to-machine (M2M) communication 19

2.2.3.2 Autonomous Robots 20

2.2.3.3 Additive manufacturing (3D printing) 21

2.2.4 Transportation 24

2.2.4.1 Automated guided vehicle system (AGVs) 24

2.2.4.2 Conveyor system 26

2.2.5 Internet of Things (IoT) 27

2.2.6 Cyber physical systems 28

3 Small and medium-sized enterprises 31

3.1 SMEs definition 31

3.2 Strengths and weaknesses of SMEs 35

3.3 The important criteria for SMEs 37

4 Selection of technologies with scoring model 39

4.1 Scoring model 39

4.2 Evaluation of the technologies 40

4.2.1 Data analysis 40

4.2.2 Identification 43

4.2.3 Workplace 48

4.2.4 Transportation 52

4.2.5 Internet of Things (IoT) 55

4.2.6 Cyber physical system 57

5 Conclusion..61
List of references 63

List of figures

Figure 1: The four stages of the Industrial Revolution. 4
Figure 2: Horizontal integration through value networks.. 5
Figure 3: Vertical integration and networked manufacturing systems............................ 6
Figure 4: End-to-end digital integration of engineering across the entire value chain. 7
Figure 5: Big data analytics layers 9
Figure 6: Service delivery models.. 12
Figure 7: Basic RFID system. 14

List of tables

Table 1: Definition of SMEs in EU. 31
Table 2: Qualitative characteristics defining SMEs compare with large companies. ..33
Table 3: The evaluation of technologies. 59

1 Introduction

1.1 Initial situation

The manufacturing industry is currently having a tendency to enormous change. A variety of persistent worldwide megatrends such as globalization, individualization, urbanization and demographic transformation lead to this change, which will significantly challenge the whole manufacturing environment in the future.[1] On the one hand, increased global-connected business activities will lead to the rise of complexity within manufacturing networks. On the other hand, the company's unstable demand and individualized products will have an impact on the production and planning process additionally.[2] These challenging requirements will drive companies to adjust their overall manufacturing approach consists of structures, products and processes.[3]

Small and medium-sized enterprises (SMEs) are the backbone of the global economy. In most countries, their number and share of employment increases. Almost 99.9% of EU companies are SMEs. They created an employment rate of 67.1% and a GDP or manufacturing value added of 57.6%.[4]

In addition, SMEs can be the basis for sustainable economic growth if they are given the right instruments and support. To remain competitive, they must constantly adapt in products as well as in production. Approaches associated to the vision of Industry 4.0 enable to help SMEs overcome these challenges. However, the success of these approaches will rely on whether SMEs will apply and implement them or not. Even so, the barriers to the introduction of the Industry 4.0 approaches and technologies remain significant.[5]

Industry 4.0 is characterized through the technological integration of cyber-physical systems in production and logistics processes and the utilization of the internet of things and services in industrial processes. The company's value creation, work or-

[1]Cf. Westkämper (2013), p. 7
[2]Cf. Abele, Reinhart (2011), p.11
[3]Cf. Spath, Ganscher, Gerlach, Hämmerle, Krause, Schlund(2013), p.42
[4]Cf. Burns (2016), p.16
[5]Cf. Issa,Lucke, Bauernhansl (2017), p.1

ganization, business models and downstream services will be influenced by advanced technologies.[6]

However, a lot of SMEs are not ready for the structural changes brought about by Industry 4.0, either because they do not have enough necessary skilled staff or because they are cautious or doubtful to a technology strategy that they do not familiar with.[7]

The lack of resources makes it difficult for SMEs to evaluate the technological maturity of the corresponding solutions and their business uses. Management is short of a methodical approach to execution. As a result, forty percent of SMEs do not have an exhaustive Industry 4.0 strategy in comparison to twenty percent within large companies.[8]

This thesis focuses on a literature review of technologies in Industry 4.0 and will find out which technologies are suitable for small and medium-sized enterprises.
Research questions:

- What technologies of Industry 4.0 are especially suitable for small and medium-sized Enterprise?
  - ✓ Which relevant technologies exist in the field of Industry 4.0?
  - ✓ What are important criteria for SMEs to implementing the technologies?
  - ✓ Which technologies can satisfy the essential criteria for SMEs?

1.2 Structure of the thesis

The remainder of the paper is organized as follows. In chapter 1, the initial situation, the research questions, the objectives and the structure are discussed. In chapter 2, technologies in Industry 4.0 are introduced. In chapter 3, the definition of Small and medium-enterprises and the strengths and weaknesses of SMEs are given, the important criteria of SMEs are also in chapter 3 discussed. In chapter 4, scoring model and the implementation of scoring model to select the suitable technologies for SMES are studied. Chapter 5 concludes the thesis.

[6]Cf. Kagermann, Helbig, Wahlster (2013), p.18
[7]Cf. Kagermann, Helbig, Wahlster (2013), p.29
[8]Cf. Schröder (2017), p.1

2 Industry 4.0

The following section is very explanatory as it describes the basic idea of the Industry 4.0 concept and its important components. Firstly the historical origination of the term Industry 4.0 is described, and then the definitions and core elements are introduced.

2.1 Definition of Industry 4.0

Industry 4.0 is the collective name of value chain organizational technologies and concepts. In a modular designed smart factory, cyber-physical systems observe physical processes, establish virtual copies of the physical world, and take decentralized decision makings. Through the Internet of Things, cyber physical systems communicate and collaborate in real time with one another and with people.[9]

Industry 4.0 is a concept that refers to the scheme of "industrial revolution" whose major purpose is to combine production processes with techniques and information and communication technologies. It is assumed that the product could be produced according to the individual requirements of the customer, for example a customer selects a sneaker with a customized sole and design or a piece of individualized designed cloth. Industry 4.0 ensures it to produce products of the highest quality and at the same price as in mass production. Intelligent, digital connected systems and production processes form the technical basis of this concept. Industry 4.0 also determines the total lifecycle of a product: from conception through design, production, usage and maintenance to final product recycling.[10]

The four industrial revolutions

Mechanization, electricity and information and communication technology (ICT) were introduced by the first three industrial revolutions into the manufacturing processes. The fourth industrial revolution will connect the real world with the virtual world to establish new production and process approaches.[11]

[9] Cf. Hermann, Pentek, Otto (2016), p.11
[10] Cf. Federal Government of Germany
[11] Cf. Kagermann, Helbig, Wahlster (2013), p.5

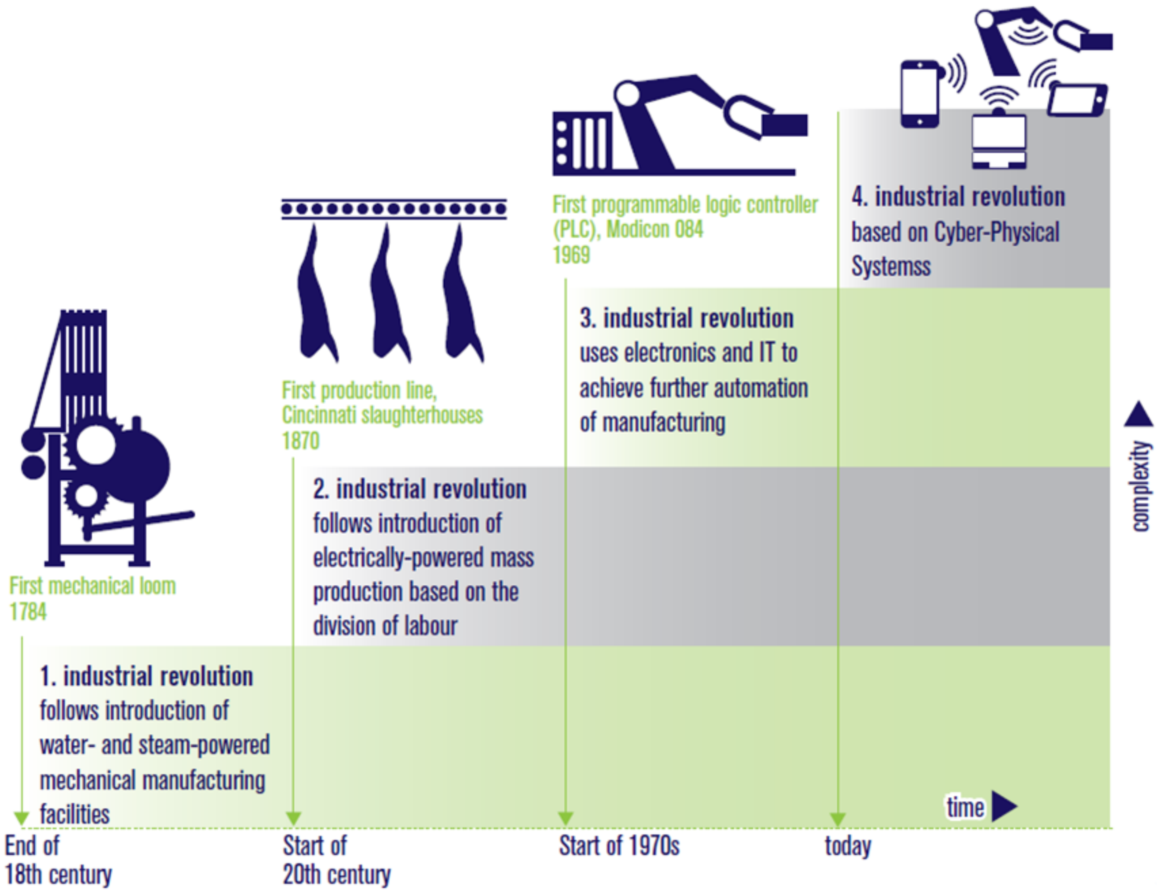

Figure 1: The four stages of the Industrial Revolution.[12]

Figure 1 illustrates the four stages of the Industrial Revolution. Industrialization started with the utilization of mechanical manufacturing facilities at the end of the 18th century, when machines such as mechanical looms completely changed the way products were made. After the first industrial revolution, at the turn of the twentieth century, the second industrial revolution began, associated with electrically powered mass-production of products due to the labor division. This was substitute by the third industrial revolution that began in the early 1970s. It continues until today. The third revolution adopted electronics and information technology (IT) to realize improved automation of manufacturing processes. Currently the fourth phase begins. It is represented by the so-called "Cyber-Physical System" (CPS). These systems are the result of deep integration of production and the satisfaction of the customers, which form the foundation of intelligent network systems and processes.[13]

In order to adapt to industry 4.0 successfully, three features should be considered: [14]

[12]Adapted fromKagermann, Helbig, Wahlster (2013),p.13.
[13]Cf. Kagermann, Helbig, Wahlster (2013), p.14.
[14]Cf. Ustundag, Cevikcan (2018), p.6

- Horizontal integration through value chains
- Vertical integration and networking of manufacturing or service systems
- End-to-end engineering of the overall value chain

1. Horizontal integration through value networks

According to the definition of the promoters group, the horizontal integration represents the integration of different information technology systems applied today in different phases of the manufacturing and business planning process that relate to material, energy and information exchanges within the company and among some companies.[15] Figure 2 shows the horizontal integration through value networks.

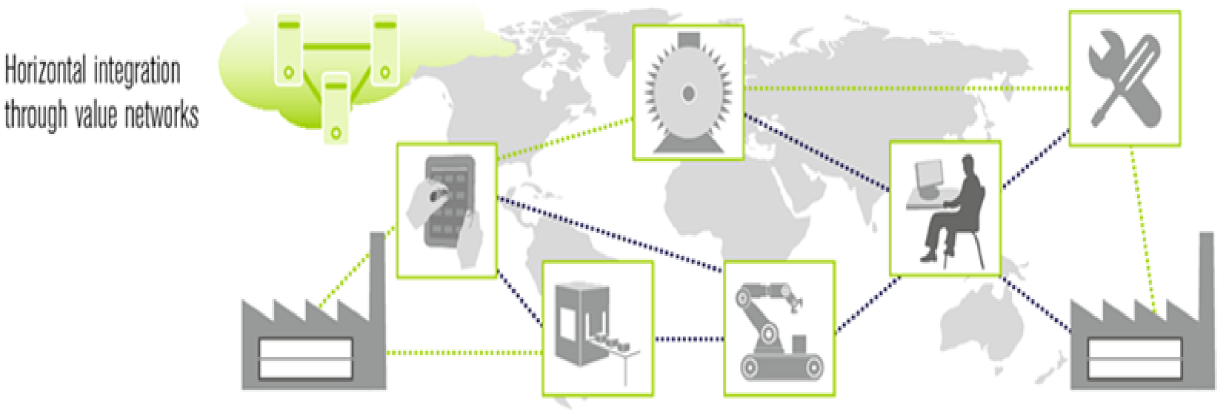

Figure 2: Horizontal integration through value networks.[16]

The association of earlier independent solutions of machines, components, and enterprises can create the new dimension of available data ("big data") through the application of the Internet of Things in real time. Applications could be the achievement a worldwide early warning system for possible bottlenecks in the supply chain of microchip.[17]

Integration of diverse information technology (IT) systems used at different stages of manufacturing and business planning processes that relate to the material, energy and information exchange both within the enterprise (for example marketing, inbound logistics, production, outbound logistics) and among different companies (value networks).[18]

[15]Cf. Kagermann,Helbig, Wahlster (2013), p.5.
[16]Adapted from Kagermann, Helbig, Wahlster (2013), p.33.
[17]Cf. Kaufmann,Forstner(2014), p.34.
[18]Cf. Kagermann, Helbig, Wahlster (2013), p.23

2. Vertical integration and networked manufacturing

The focus of vertical integration is on integrating different IT systems at diverse hierarchical levels of the enterprise to create an end-to-end solution for the manufacturing system.[19] At present the hierarchical levels include sensors and actuators, production management systems, control systems, enterprise resource planning (ERP) and manufacturing execution systems (MES). The adoption of cyber physical systems disintegrates the automation pyramid from a inflexible and hierarchical system into a decentralized and flexible organized CPS based automation system, where the product dominate the production process by itself.[20] Figure 3 shows the vertical integration and networked manufacturing systems.

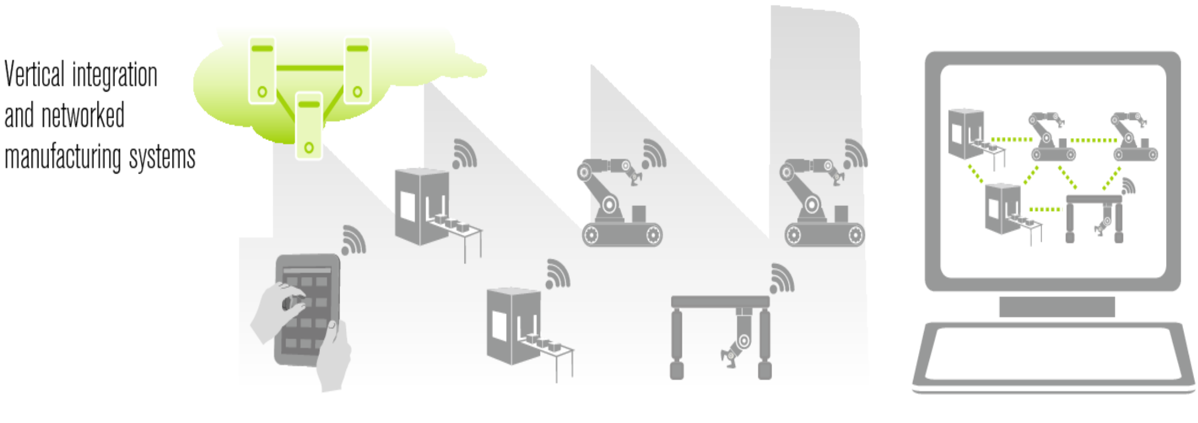

Figure 3: Vertical integration and networked manufacturing systems.[21]

Moeller states an example of the adoption of vertical integration and network manufacturing system can occur in customer-specific manufacturing and how individual customer needs are met. Tomorrow vehicles will turn into smart products that will automatically move from one cyber- physical system supported processing module to another through the assembly shop. The dynamic reconfiguration of the production lines allows the equipment in which the vehicle is installed to be mixed and matched. Additionally, individual changes can be made at any time for example the installation of a seat from another vehicle series when logistical problems such as bottlenecks occur.[22]

Vertical integration demands intelligent networking and digitalized business units at different hierarchical levels of the organization. Thus, vertical integration preferably

[19]Cf. Kagermann, Helbig, Wahlster (2013), p.33.
[20]Cf. Bettenhausen,Kowalewski(2013).
[21]Adapted from Kagermann, Helbig, Wahlster (2013), p.34.
[22]Cf. Moeller, D.P.F. (2016).

allows conversion to a smart factory in an extremely flexible way and offers small batch production and more individualized products with appropriate profit levels. For example, intelligent machines build a self-automated ecosystem that could be dynamically managed to influence the production of various product types and a large number of data can be processed to simply manipulate the manufacturing process.[23]

3. End-to-end digital integration of engineering

Nowadays information technology (IT) systems have diverse interfaces that allow data to be exchanged between various systems, which deal with the different steps in the product and manufacturing systems lifecycle and restrict the flexibility of the value chain from design to customer. The CPS application allows the establishment of model-based development, enabling for the deployment of an end-to-end approach. The approach covers every perspective from customer needs to product architecture and production of finished products. In the end-to-end engineering tool chain all interdependencies could be determined and expressed.[24] Figure 4 shows the end-to-end digital integration of engineering across the entire value chain.

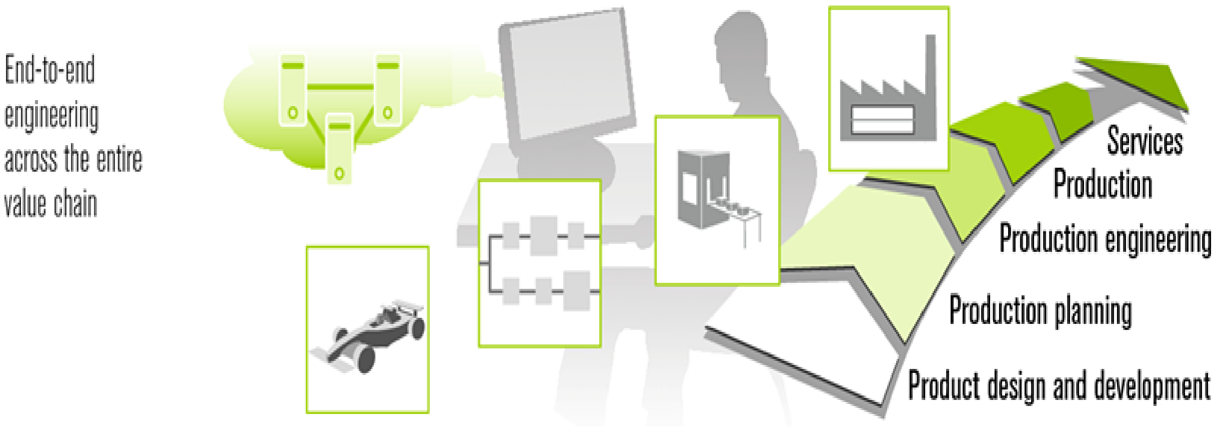

Figure 4: End-to-end digital integration of engineering across the entire value chain.[25]

End-to-end digital system engineering and the optimization of value chain means that customers don't need to select product from a predefined product line identified by the manufacturer any more, but can combine and customize individual features and parts according to their specific requirements.[26] Thanks to the end-to-end

[23]Cf. Ustundag, Cevikcan (2018), p.6
[24]Cf. Kagermann, Helbig, Wahlster (2013), p.33.
[25]Adapted from Kagermann, Helbig, Wahlster (2013), p.33.
[26]Cf. Kagermann, Helbig, Wahlster (2013),p.35.

value chain, this holistic engineering approach enable to integrate customer individual products to achieve higher customer satisfaction at lower costs.

Industry 4.0 is possible to positively impact individual customer needs, production flexibility, resource productivity and efficiency, optimization of decision-making, added value from new services and work-life balance of human labor.[27]

2.2 Technologies for Industry 4.0

There are many technologies that are implemented in Industry 4.0. This section introduces the main technologies in Industry 4.0. The technologies are categorized in the groups of data analysis, identification, workplace, transportation, Internet of things and cyber-physical system.

2.2.1 Data analysis

2.2.1.1 Big data and analytics

Production needs a large space for different data, such as historical data, sensor data, and production data. These large amounts of data referred to as big data are saved in the cloud, they are extremely essential for analysis, production diagnosis, and they are the foundation of decision making.[28]

In contrast to the data processing in relational database, the following three attributes should be taken into account in order to create big data infrastructure that can be successfully executed with Industry 4.0 elements: [29]

- Big data acquisition and integration;
- Big data processing and storage;
- Big data mining and knowledge discovery in database.

The stage of big data acquisition and integration involves collecting of data from for example RFID readers, intelligent sensors and RFID tags. Big data processing and storage allocates data from real-time and non-real-time through removing, transformation, and integration, these data are in form of structured and unstructured. Big data mining is used by collecting, categorization, combination and prediction with the help of decision trees, support vector machines, genetic algorithm, and rough set theory for big data excavation and knowledge invention. [30]

[27]Cf. Kagermann, Helbig , Wahlster (2013), p.19
[28]Cf. Mindas, Bednar (2016), p.23
[29]Cf. Ustundag, Cevikcan (2018), p.12
[30]Cf. Ustundag, Cevikcan (2018), p.12

The techniques of data mining must be used when collecting data from different sensors. This information provides estimation of the present status and configuration of various machines, environments, and other related conditions that could influence the manufacturing as seen in smart factories.[31]

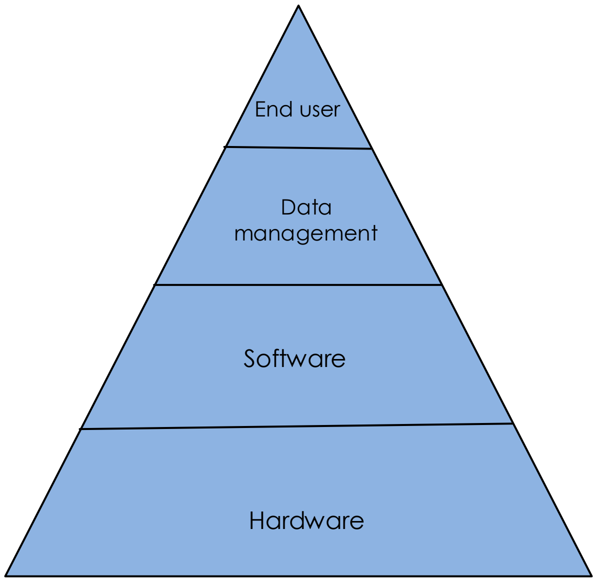

Figure 5: Big data analytics layers[32]

Big data systems can be taken into consideration to have four main layers, everyone is absolutely necessary. Figure 5 shows the four layers. The levels are discussed as follow:[33]

- Hardware: Several elements that determine the hardware stack are for example the servers that supply the backbone of computing, the storage device where the data is saved and the network interconnections between various server components.
- Software: The next level represents the software resources that accelerate analysis on the datasets hosted in the hardware level, for example hadoop and NoSQL systems.
- Data management: The next layer formed by data encoding, administration, access, agreement, and other attributes that manage all enterprise and production environments and reduce operational complexity.

[31]Cf. Ustungdag, Cevikcan (2018), p.10
[32]Adapted from Dasgupta (2018), p.13
[33]Cf. Dasgupta (2018), p.13

- End user: The last perspective of a big data analytics are formed by the end user of the analytics software. Because the efficiency of the data platform is only as good as the level of the ability to effectively use the data platform and solve business-specific use cases. This is where the role of the practitioner who using the value added analytics platform comes into play.

Today's technology allows us to gather data at incredible speed both in quantity as well as in diversity. There are diverse sources of data generation, but in the background of big data, the main sources are from sensors, social networks and data warehouses.[34]

In manufacturing industry, a large amount of data is expected to increase in proportion with the use of smart objects and their components, for example sensors and sensor networks.[35] While manufacturing companies begin to use advanced information technologies to accelerate their information flow, they collect a large amount of real-time data related to manufacturing from a variety of sources. The data collected during research and development, production, operation and maintenance grows exponentially.[36]

The volume of data is very large, it requires fast processing, and needs an association of different data sources in multiple formats. The analysis of all this data gives companies a significant competitive advantage so they can meaningfully evaluate the overall processes.[37]

In the future, the conversion from "big data" into valuable "smart data" will be a major challenge, ultimately improving the efficiency of the process when it is used properly[38]. The use of advanced data analysis techniques to automatically detect relationships, meanings and patterns can create further benefits.[39]

2.2.1.2 Cloud computing

Computing has been converted by cloud computing. Cloud computing becomes an essential trend in the technology development and many specialists hope that the processes of information technology and the IT markets will be reformed through cloud computing. Cloud computing technology enables users to access programs,

[34]Cf. Dasgupta (2018), p.17
[35]Cf. Schöning (2014), p. 548
[36]Cf. Ustungdag, Cevikcan (2018), p.10
[37]Cf. Ustungdag, Cevikcan (2018), p.10
[38] Cf.Kaufmann, Forstner(2014), p. 365
[39]Cf. Weber(2013), p. 10

storage and application development platforms via the Internet by using diverse devices including PCs, smart phones and laptops through the services of cloud computing providers.[40]

In cloud computing, data and computation are manipulated somewhere in the "cloud". The cloud is several collections of data centers that owned and maintained by a third party. Cloud computing indicates the hardware, applications and system software deployed via the Internet as a service. If the cloud is accessible to the public in a pay-as-you-go way, it is a public cloud. When the cloud infrastructure is executed only for one company or an organization, the term private cloud is used. The combination of these two types is referred to as a hybrid cloud. In hybrid cloud, a private cloud can retain high availability of service by enlarging its systems with externally supply resources from the public cloud, when rapid fluctuations of workload or hardware errors occur.[41]

Generally, there are three categories of cloud providers:[42]

- Infrastructure as a Service (IaaS): providing web-based access to storage and computing power. Customers do not have to administrate or control the fundamental cloud infrastructure, but they can control the operating system, storage and arranged applications. IaaS means computing resources as a service. Customers enable to realize faster time to market and service delivery. Key examples are GoGrid, Flexiscale and Layered Technologies.
- Platform as a Service (PaaS): offering the tools to create and host web applications to developers. PaaS is alike IaaS, but also consist of operating systems and desired services for specific applications. It supplies a simpler way to develop business applications and different services over the Internet. Examples are Google AppEngine and Microsoft's Azure.
- Software as a Service (SaaS): applications that are accessed by a large number of client devices by a thin client interface like a web browser. With SaaS users can implement applications remotely from the cloud. Examples of the key providers are Oracle, IBM and Microsoft.

[40] Cf. Furht, Escalante (2010), p.3
[41] Cf. Antonopoulos, Gillam (2010), p.4.
[42] Cf. Antonopoulos, Gillam (2010), p.4.

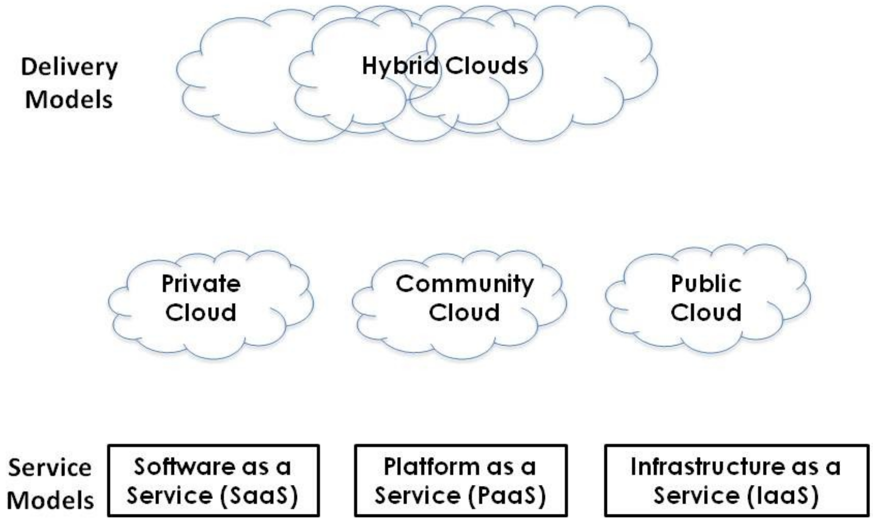

Figure 6: Service delivery models.[43]

Figure 6 illustrates the service models and delivery models. All the services are able to be delivered on any of the cloud delivery models. The demands of cloud based processing are listed as follow:[44]

- Data-driven applications run in a cloud-based infrastructure, and each supply chain component and user is connected via the cloud system;
- Use separate cloud database function to analyze notifications and exceptions with real time data;
- Making full use of big data to optimize system performance on the basis of external and unexpected changes;
- Users require a connected device to check the essential information on cloud, and have authorized access to available applications and global data.

Data from the manufacturing process runs altogether on the server in cloud systems, then the data is analyzed and returns to its destination. Apple's Siri is an example of this feature. A voice instruction is recorded via the microphone, then the voice record will be sent to the server, it is evaluated there, and the answer is sent as a

[43]Adapted from Josyula, Orr, Page (2012), p.12.
[44]Cf. Ustundag, Cevikcan (2018), p.10

control instruction to the sender unit.[45] These features can be provided as a service on a cloud-based digital platform. It is even imaginable that these services will be acquired in the form of application software. Apps are solutions of small software. They are provided with predefined functions, can be used in limited terms of reference, and are comparable to the concept of service. [46]

Advantages of cloud computing

Cloud computing technology offers many benefits such as cost savings, high availability, and simple scalability.[47] Cloud computing provides many benefits to manufacturers, for example it is an easy-to-manage infrastructure as the data center owns homogenous hardware and system software. Cloud computing promises lower costs, rapid implementation, and increase flexibility by applying combination of technologies.[48]

High availability, easy scalability and fast network connectivity are the characteristics of cloud computing. Therefore, using the defined interfaces to provide functionality is the underlying technology for achieving the Industry 4.0 solutions.[49]

2.2.2 Identification

2.2.2.1 Radio frequency Identification (RFID)

Reyes defines Radio Frequency Identification (RFID) as an automatic identification technology that can be used for identifying, tracking and tracing objects or products with the help of radio frequency.[50]

Effectiveness and smoothness are brought by the IT technology and its products into the logistics system. One of these technologies is Radio Frequency Identification (RF-ID). The major difference between RFID and barcode systems is that RFID does not require to be scanned on the product. RFID can save a lot of time for manual activities. When the customer pushes the trolley out of the market through the exit, the RF-ID system can automatically recognize the number of items input in the tags.[51]

[45]Cf. Verl, Lechler(2014), p. 238
[46]Cf. Bildstein, Seidelmann (2014), p. 587
[47]Cf. Furht, Escalante2010), p.3
[48]Cf. Antonopoulos, Gillam (2010), p.3.
[49]Cf. Fallenbeck, Eckert(2014), p. 404
[50]Cf. Reyes (2011), p.3.
[51]Cf. Tseng, Yue, Talor (2005), p.1670.

Tags, antennas, readers and communication infrastructure are included in the fundamental RFID system. The RFID tag is attached to an item. There are active and passive RFID tags.[52] Essentially, the RFID technology operates non-contact and includes small transponders (also called tags) which connect to objects (e.g., objects, items, trays, containers) and reading and writing devices, which are wirelessly connected with transponders. There is mobile data storage on a memory chip and an antenna in the transponder.[53] These transponders can be used to almost any tangible object, because their volume is able to be compacted to a little black spot on the fingertips.[54]

Figure 7 illustrates the function of RFID. An object is attached with transponder or tag, an RFID reader interact with the tag to determine the object. The Tag consists of information about the object such as model number, serial number, or other features to identify it as needed. The information of the object is able to be stored in the tag to recognize or differentiate this object from other objects, or to allow tracking of the movement of the object.[55]

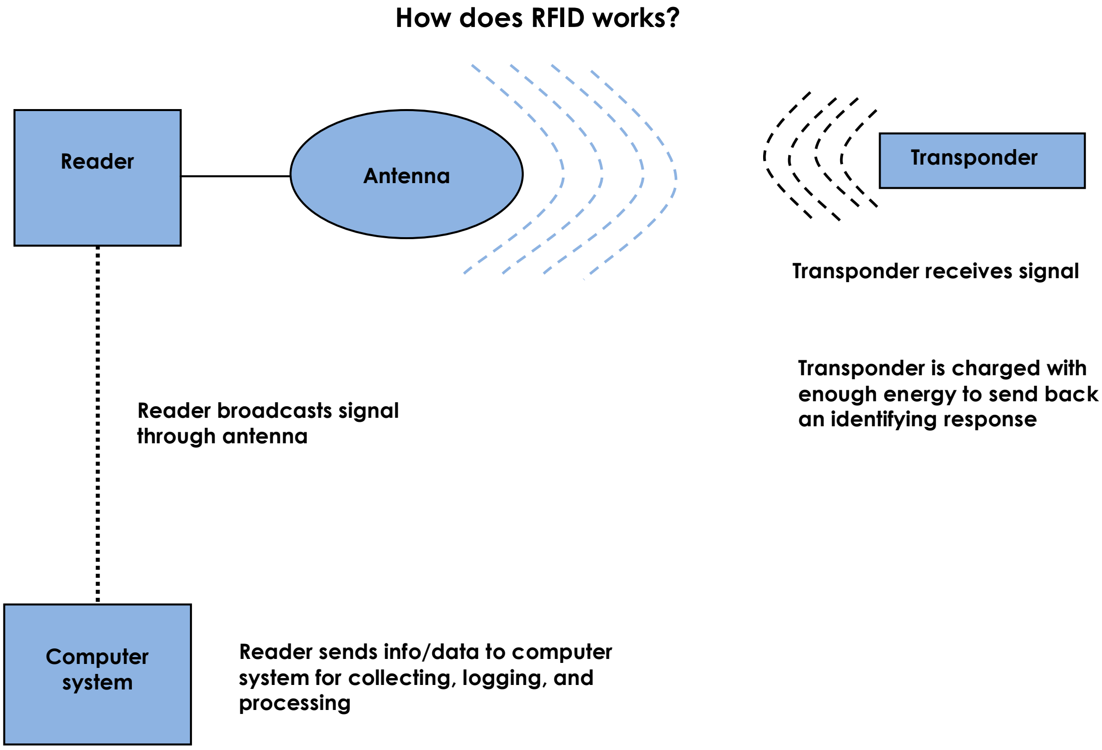

Figure 7: Basic RFID system.[56]

[52] Cf. Reyes (2011), p.5.
[53] Cf. Herzog, Schildhauer(2009), p. 78
[54] Cf. Glotzbach (2009), p. 14
[55] Cf. Reyes (2011), p.5.
[56] Adapted from Reyes(2011), p.5.

Technological advance of radio identification is able to expand the classical functionality of RFID with respect to an enhancement of decentralized intelligence, because almost all of the critical information is currently stored in one database. In addition to the transfer of a sole identification number, some other information can as well be stored and interchanged with other systems. In production logistics, this data-on-chip principle enables to storage data from the destination, content of a load carrier of the transportation,[57] tracking and storage of raw materials and spare parts, collection and storage of production data, data analysis, automatic production control for flexible requirements, warehousing management of the products in the factory.[58]

In addition, the physical object can be provided with a digital product memory, this memory is able to be used to assure a complete traceability of objects or optimize the production process, while offering information about historical production data and other production steps, for example applying for bill of materials (BOM).[59] Another application of RFID is to determine the location of an object within a factory. Transport systems such as AGVs are able to be equipped with reading devices in order to read RFID transponders that are embedded in the plant. Therefore, the AGV can be tracked at all times within a predetermined range of motion. In order to continue this idea consistently, the materials transported by an AGV is also able to be positioned at all times, when they are within the reading range of the readers of AGV (if the material also has an RFID transponder).[60]

Widely modified RFID-based technologies can be successful implemented in smart factories and processes. For example, an intelligent identification label was carried out by the Hologram Company, which allows electronic identification of customized goods simply and dependably either on the goods or on the package of the goods. Further example is the advanced assembly line of the floor cleaner from Alfred kärcher GmbH, where the QR code embedded with the RFID chip is used to track the product from the initial stage of the manufacturing.[61]

[57]Cf. Günthner, Durchholz, Kraul, Schneider(2008), p. 16
[58]https://www.hopelandrfid.com/industry-4-0-smart-manufacturing_n40
[59]Cf. Botthof, Bovenschulte(2011), p. 3f.
[60]Cf. Günthner, Durchholz, Kraul, Schneider(2008), p. 16
[61]Cf. Ustundag, Cevikcan (2018), p.14

Advantages of RFID

RFID technology has several great advantages and disadvantages with regard to barcodes. Products with RFID tags are also able to be read even if the tags are not directly approachable to the reader. Data is able to be read from the range of distance up to 10 meters. The reading speed is very high so that hundreds of tags can be read in one second. Unlike bar codes, which are able to be easily broken and therefore miss information, RFID tags are able to highly resist to physical damage. The necessary information can be added in the RFID tag relevant species subsequently.[62]

Reyes mentioned that improving speed, security and efficiency in the supply chain, and decreasing inventory levels, labor cost and out-of stock goods within warehouses and retail stores are the benefits of RFID. Other possible benefits are including:[63]

- ✓ Increasing accuracy and security of information sharing across the supply chain;
- ✓ Reducing storage, handling, and distribution costs;
- ✓ Increasing sales by reducing in out-of-stock goods;
- ✓ Improving cash flow by increasing inventory turns and improving adoption of assets, and improving service and satisfaction of customers;
- ✓ Increasing cooperation and planning between supply chain collaborators.

2.2.2.2 Sensors and actuators

Unidentified signals and variables of engineering systems and their environments are needed to measure by sensors. In essence, sensors are required to monitor and understand the system. This knowledge can be used not only to operate or control the system, but also for a lot of other objectives such as process monitoring; product testing and qualification; product quality evaluation; detection and diagnosis of errors; generation of warning and monitoring. A general application for sensors is, for example, in vehicles where a large diversity of sensors is employed in the power train, safety, comfort and driving assistance.[64]

[62]Cf. Hozdic (2015), p.33
[63]Cf. Reyes (2011), p.8.
[64]Cf. Sliva (2016), p.1

Actuators are required to manipulate a plant. As another category of actuators, control actions are executed by control actuators, and they run particularly control devices.[65]

Sensors do not work separately of each other, but are usually part of a larger system that includes controller signals and various digital and analog circuits for signal processing. The system could be a measuring system, a process control system or a data acquisition system.[66]

Sensors and actuators are the fundamental technology of embedded systems because the whole control unit usually consists of one or more microcontrollers that observe the sensors and actuators that are required to communicate with the real words. In industrial adjustment of Industry 4.0, embedded systems similarly includes a control unit, a number of sensors and actuators that are interconnected to the control unit. Signal processing function is conducted by the control unit in such systems. Because the intelligent sensors and actuators are created for industrial environment, the sensors deal with the signal processing and the actuators independently check the current production status and correct them if it is needed. These sensors transfer their data, for example through field buses to a central control unit. In this regard, sensors and actuators are able to be determined as the main components of the whole embedded system.[67]

Manufacturing and production engineering is a wide range of applications with various sensor and actuator technologies. Examples are including factory robots, automated guided vehicles (AGVs), machining centers, rapid prototyping systems, modern computer-numerical control (NCN) machine tools, and micromachining systems. High-precision motion control, monitoring product quality and machine instrument are especially essential in these applications, where advanced sensors and actuators are required.[68]

An example is the power and robotics firm ABB which embrace the predictive maintenance concept that adopts connected sensors to monitor the maintenance needs of its robots across five continents and activate repairs before parts are broken.[69]

[65]Cf. Sliva (2016), p.1
[66]Cf. Hozdic (2015), p.32
[67]Cf. Ustundag, Cevikcan (2018), p.15
[68]Cf. Sliva (2016), p.5
[69]Cf. Buntz (2017)

The advantages of sensors and actuators are:[70]

- ✓ Track across the overall production or service systems in real time.
- ✓ Continuous data collection and documentation to support big data analytics, knowledge extraction and deep learning.
- ✓ Improve system availability by monitoring of conditions.

2.2.2.3 QR code

The Quick Response Code (QR code) is a two-dimensional graphic consists of small black squares. They are the same with the barcode on the back of a product, but they do not need a red laser beam that applied to scan the barcode on goods. QR codes provide a special set of information for those who scan them. They are initially applied in manufacturing industry. Nowadays QR codes are located in many different places for many various purposes. When people scan the QR code, they are allowed to access content, which is hosted over the Internet.[71]

The digital connection between the scanned QR code and the information in the web site is a modus called "hyperlink". The links on the website and the linked websites are all digitized; it means that they build up by electronic bits and bytes. When an item is scanned, whatever it is, the item is real. This is “hard”, thus the connection between the "real" object and the "virtual" information offered by the QR code is often called a "hard-link". This is also referred to as a "physical world hyperlink".[72]

The QR code was created in Japan to follow vehicle parts. The original purpose of QR code was for inventory, but its possibilities and utilization expands far beyond that initial function. They consist of far more information than the normal barcode, which represents information and can be read only horizontally.[73]

The QR code has progressed well since the first use for tracking auto parts. QR codes are able to offer or result in the following, and much more:[74]

- Information of products consists of price, country of origin, user manual, service location, warranty, power consumption during operation and in its manufacture, safety warning.

---

[70]Cf. Ustundag, Cevikcan (2018), p.16
[71]Cf. Burns (2016)
[72]Cf. Winter (2010), P,20
[73]Cf. Brabazon, Winter, Gandy (2014), p.7
[74]Cf. Winter (2010), P,20

- Food products: Agricultural information contains planting locations, producer reports, lot number and processing locations.
- Transportation: Car, train, bus, plane, subway, schedules, and foot navigation.
- Retain businesses: Website, reviews such as Yelp and Google places, special sales, discount coupons, subscription to mailing lists, products and services lists.

The main advantage of QR codes is that they can hold more information in a smaller space as they are able to be read vertically and horizontally. In addition, they can be read in diverse angles, and the algorithm utilized to generate them is able to realize a larger margin of error (between 7% and 30%).[75] In one QR code there can be up to 4,296 characters of information included. [76]

2.2.3 Workplace

2.2.3.1 Machine-to-machine (M2M) communication

Machine-to-Machine communication refers to the fundamental communication network with limited or without human intervention that connects computers, sensors, actuators, embedded processors, and mobile devices.[77]

M2M involves technology that enables devices to communicate with each other over wired and wireless systems. M2M apply a device such as a sensor or measuring instrument to record an event (e.g., inventory level or temperature) to an application which interprets the recorded event into meaningful information. This event is transferred via a network that offers remote connectivity for the devices.[78]

According to Deutsche Telekom there are four important steps in every M2M solution:[79]

1. Collecting data via sensors;
2. Delivering data to a central server through mobile or fixed-line connection or an alternative network;
3. Evaluating data;
4. A corresponding intelligent reaction.

[75]Cf. Brabazon, Winter, Gandy (2014), p.7
[76]Cf. Winter (2010), P,20
[77]Cf. Misic, Misic (2015), p.2.
[78]Cf. Misic, Misic (2015), p.4.
[79]Cf. Deutsche Telekom.

As this process creates a large amount of heterogeneous data, the development of M2M solutions is always combined with technologies such as big data and cloud computing.[80]

The fundamental principle of M2M communication according to two views: Networked machines are more profitable than isolated machines and can support more autonomous and smart applications when several machines are linked to each other.[81] Currently, many M2M applications are emerging in diverse areas, for example smart robots, manufacturing systems, cyber transportation systems, and smart networks.[82]

M2M solutions for remote machine monitoring and control in industrial automation can significantly increase the efficiency. Although it is used on the other side of the world, the company can also control the equipment and machines. A particular module with an M2M SIM card saves the data provided by the device and then the data is sent encrypted over a mobile network to the cloud. The online portal displays error messages on a PC or tablet, runtime and consumption in real-time in order to make a respond to breakdowns early and reduce downtimes.[83]

Advantages

M2M is used to reduce costs, increase productivity and increase security or safety.[84] The important advantage of M2M solutions is that they are able to independently identify and respond to critical situations. If a machine fails or the shipping container arrives at the destination, the real persons are informed at the terminal point of the reaction chain. M2M communication is attractive for many industries and applications.[85]

2.2.3.2 Autonomous Robots

Robots are can perform complex actions, making decisions, interacting with the environment, and normally respond believable. The visual abilities of robots play an essential role in their action and help them to effectively operate the obtained information.[86]

---

[80]Cf. Deutsche Telekom.
[81]Cf. Misic, Misic(2015), p.2.
[82]Cf. Misic, Misic (2015), p.2.
[83]Cf. Deutsche Telekom.
[84]Cf. Boyle, Höller, Tsiatsis, Mulligan, Karnouskos, Avesand(2014), p.11.
[85]Cf. Deutsche Telekom.
[86]Cf. Arvanitis, Lalos, Moustakas, Fakotakis (2017), p.11

The definition of robots is very wide. It consists of industrial robotic manipulators, for example manipulators for assembly, painting or welding operations, in case they contain all three of these elements. Nowadays many of the industrial robots are equipped with sensors and computer vision and have integrated processors to permit for certain autonomy. Robots can be designed in a large diversity of shapes and sizes, with different levels of intelligence, autonomy and ability to move.[87]

Intelligent robots substitute humans with easy and repeated workflows within a closed zone. In industry 4.0, robots work together with humans with the help of intelligent sensor human-machine interfaces on interconnected tasks. The adoption of robots including diverse functions such as production, office management and logistics is increasing dramatically, so that they are able to be remotely dominated.[88]

When a problem takes place, the operator receives on his mobile device a message, which is managed by the workflow module that connected to the remote device, so that the operator can find out the problem and give the device commands to continue production until he returns to work tomorrow. As a result, the factory operates 24 hours per day, but the operators need to work only during the day.[89]

2.2.3.3 Additive manufacturing (3D printing)

Additive Manufacturing refers to a series of emerging technologies in which three-dimensional objects are produced directly from a digital model by additive processes, in particular by using suitable polymers, metals or ceramics to store and join products. More specifically, additive manufacturing is originated by creating computer aided design (CAD) and modeling that assemble a series of digital characteristics of the product and offer the industrial machine a description of the products.[90]

The transmitted description is executed by the machine as a blueprint to build an object by adding material layers. In microns measured layers are added by a lot of times up until a three-dimensional item is created. The raw material is able to be in the form of a liquid, a film or powder and in particular is made up of plastics, metals

[87]Cf. Bekey (2005),p.3
[88]Cf. Roland Berger Strategy Consultants. (2014), p.8
[89]Cf. Roland Berger Strategy Consultants. (2014), p.8
[90]Cf. Ustundag, Cevikcan (2018), p.8

ceramics, or other polymers. In this regard, additive manufacturing consists of two degrees as software for gaining the 3D items and material obtaining side.[91]

The technology of additive manufacturing essentially includes three basic steps:[92]

1. Develop a computerized three-dimensional (3D) solid model and transform it into a standard AM file format, for example the traditional Standard Tessellation Language (STL) or a updated AM format;
2. Then send the file to an additive manufacturing machine where the modification of position and direction or simply to scale the part is controlled;
3. On the additive manufacturing machine, the part is then built up layer by layer.

The model was immediately used to provide information as the so-called "3F" on the form, fit and function. The original model was applied to help better understand the shape and common purpose of the design (form). Increased accuracy needed for assembly purpose (fit). Increased material functions indicate that parts can be processed correctly so as to evaluate them based on how they work (function).[93]

Advantages and disadvantages

Srivatsanand and Sudarshan suggest that additive manufacturing has the following advantages and disadvantages to provide:[94]

- Material utilization efficiency: In contrast to traditional manufacturing in the basis of subtractive theory, where a big number of materials need to be eliminated, additive manufacturing enables effective and efficient utilization of raw materials by building parts layer by layer. The remained materials are usually used again with minimum processing.
- Resource utilization efficiency: Besides the main machine tools, traditional manufacturing processes often need additional resources such as jigs, cutting tools, fixtures and coolants, but additive manufacturing does not need these additional resources. Consequently, different parts can be manufactured by small manufacturers that located near from the customers. This situation offers the opportunity to improve the dynamics of the supply chain.

[91]Cf. Ustundag, Cevikcan (2018), p.8
[92]Cf. Srivatsan, Sudarshan (2016), p.4
[93]Cf. Gibson, Rosen, Stucker (2015), p.3
[94]Cf. Srivatsan, Sudarshan (2016), p.25

- Flexibility of parts: Since there are no tool constraints in additive manufacturing, parts with complex attributes is usually able to be created in a unique piece. This makes it possible to assure simplicity and repeatability of manufacturing without affecting the function of a part. In addition, it is presently possible to construct individual components with different mechanical performance, for example one end portion of a part is flexible and the other end portion is harder. This provides opportunities for new design innovations.
- Flexibility in production: The machines do not need expensive setups and are therefore economical for small batches production. The entire quality of the part depends more on the process applied than on the capabilities of the operator. This means that the production and customer requirements can be synchronized. In addition, problems related to the balance of line and bottlenecks of production are removed as complex parts are able to simply be manufactured in an individual piece.

Advantages of 3D printers consist of the manufacturing of products with difficult shapes or complex geometries. Therefore, parts can be produced that were previously unprofitable or whose production is related to technical or economic reasons with considerable costs.[95] As mentioned earlier, the type of production will be changed by 3D printers. Until now, the product has been made from blanks and the waste content is more or less large. In contrast to this, 3D printers continually build up a single part and therefore minimize the material usage.[96]

However, additive manufacturing, especially in mass production, could not completely compete with traditional manufacturing, mainly for the following reasons:[97]

- Size Restriction: The additive manufacturing process typically employs powder a liquid polymer that is inlaid resin or plaster to create the layer of objects. The application of these materials indicates that no large objects are able to be produced due to the lack of material intensity. In addition, large objects become not practical if considering the large amount of time needed completing the build process.
- Presence of imperfections: Parts made with additive manufacturing processes usually have a ribbed and rough surface finishing. This phenomenon is mainly

[95]Cf. Huber (2016), p.35
[96]Cf. Huber (2016), p.34
[97]Cf. Srivatsan, Sudarshan (2016), p.26

because of the fact that plastic beads or large powder particles are gathered on top of one another. This unfinished appearance needs further surface treatment by polishing or machining.

- Cost: The investment of additive manufacturing equipment could be high.

There are already devices for consumers for fewer than 1000 Euros. In the industrial environment, depending on the area of application, the costs for purchasing the devices is often equal to six digits. Such machines permit to produce economic and individual products (not just in small amount of products), even in decentralized positions.[98]

2.2.4 Transportation

2.2.4.1 Automated guided vehicle system (AGVs)

Automated guided vehicle system (AGVs) refers to an driverless material handling system, which utilized for moving raw materials, semi-finished or finished products that produced in batches or mixes mode production environment. Since the introduction, the utilization of AGV has increased significantly. The number of application areas and variants of types have enormously grown. AGVs are able to be applied in both internal and external environments, for example in manufacturing areas, transshipment and external transport regions. In the area of production, the AGVs transport all materials types associated with the production process.[99]

Ullrich addresses that AGVs has became a core element of internal logistics within an organization nowadays. The technical standard and the present experience level with this automation technology have made AGVs available in nearly all industrial branches and production areas. The fast development of sensors and regulatory technologies as well as microelectronics paved the way for AGVs.[100]

There are non-contact sensors and electronic guidance in AGVs. They are manipulated by a standard PC containing a microprocessor or a programmable logic controller (PLC). Laser and Magnetic navigation are the so-called classic "free" navigation technologies. WLAN has accepted as a way of data transmission. Today's AGVs are reliable, proven internal logistics approach. Manufacturers can select from

[98] Cf. Huber (2016), p.34
[99]Cf. Fazlollahtabar, Saidi-Mehrabad (2015), p.1
[100]Cf. Ullrich (2015), p.1

amount of well-tested technologies and integrate these technologies to produce reliable, high-performance, and recognized products.[101]

When a dispatching decision is executed, the route and schedule of the AGV should be set to move the job from its starting point to the terminal point within the AGV network. The route indicates the way the AGV ought to take when collecting or delivering goods. The associated timeline indicates the arrival and departure times of the AGV at every part, pick-up and delivery point and the crossing of the route to make sure a non-collision route. A certain route and a schedule selection are valid for the property of the system. The longer it needs to transport a task, the fewer tasks are able to be transported within a certain period of time. Therefore, one of the goals of the selection of AGV route is to reduce transport time.[102] The literature is therefore dedicated to the development of conflict-free ways for the AGV. The AGV can reach its terminal point as early as possible without conflicting with each other in the conflict-free routes.[103]

In essence, AGVs can transport almost every load. The AGVs can be used for all operations, in which pallets, containers, bales, sacks or similar items are transported. The main features of AGVs include: [104]

- Transportation of materials, loose parts and pallets for production processes;
- Temporary storage of materials;
- Distribution of materials or semi-finished goods to different workstations in the work shop;
- Retrieval of items from a workstation;
- Collection of parts for assembly;
- Moving finished goods to storage or docks.

Advantages

The utilization of AGVs has following advantages:[105]

- The utilization of AGVs reduces labor cost;
- AGVs are flexible and can move single or multiple loads;

[101]Cf. Ullrich (2015), p.10
[102]Cf. Fazlollahtabar, Saidi-Mehrabad (2015), p.4
[103]Cf. Fazlollahtabar, Saidi-Mehrabad (2015), p.4
[104]Cf. Bandyopadhyay (2018), p.27
[105]Cf. Bandyopadhyay (2018), p.28

- AGVs are smart vehicles because they can determine the path selection or direction based on the different limitations in the network at a specific time;
- The utilization of AGVs need to spend less time;
- The utilization of AGV can significantly reduce costs of production and warehouse.

2.2.4.2 Conveyor system

Conveyors are one subcategory of the large group of material handling equipment. Like all material handling equipment, conveyors do not increase the value to the components, products to be moved. That means the products will not be shaped, processed, formed or changed in any way. They are completely service processes and as a service they indirectly affect the product cost as part of the operating costs. The following is a list of some of the main goals of implementing conveyors:[106]

- Minimize actual manual handling process.
- Execute all handling processes at the lowest rational cost.
- Prevent manual actions as much as possible.
- Reduce the workload of all manipulators.
- Improve the ergonomics of each operator.
- Improve the work flow between operations.
- Offer routing choices for intelligent workflow.
- Improve throughput.
- Carry goods when do so manually it would be unsafe.

Parts can be moved by conveyor systems between automation systems and within one automation system, for instance, the movement of components within the assembly system or the loading of cartons from the packing line to the robot stack systems. A stable movement between two locations along a predetermined pathway is supplied by conveyors. They could be located on the ground or positioned overhead. The selection of the conveyor system based on the product that need to be moved, the available space, and the access needed to other operations and de-

[106]Cf. McGuire (2009), p.1

vices. They are especially good for moving a large number of products and can offer buffers or temporary storage among certain operations.[107]

2.2.5 Internet of Things (IoT)

The Internet of Things enables things and objects such as sensors, actuators, mobile phones and RFID to interact with each other and collaborate with the neighboring intelligent parts, to achieve common objectives.[108]

The Internet of Things uses a variety of things to provide services to a variety of applications by using identification, data collection and processing and communication functions. In summary, the Internet of Things is a base installation that connects life and nonlife objects, and communicates with them over the Internet, save data through sensors in the cloud system, and offer real-time information to human or machines.[109]

The Internet of Things is tightly associated with the Internet, wireless sensor networks and mobile communication networks, including RFID, sensor technology, big data, cloud computing and near field communication.[110]

The Internet of Things adds a new scale to the theory of communication, as time goes on human-to-human, human-to-machine communications and machine-to-machine communication can take place via the Internet of Things. IoT links the real world with the virtual world and makes efficient use of M2M interaction. The communication of things is called the speech among things. Assume that everything in the future wants to keep in touch to the Internet. The conversion from the information era to the "connected age" has begun. This conversion process, which started with the adoption of Internet to our lives, has resulted in developments, for example the idea of "connected things" that occur in human lives in the way where there is a unique ID and IP address for each object. The object is connected to each other through the network, exchange information and use the embedded sensor system to transmit environmentally relevant data.[111]

[107]Cf. Wilson (2015), p.41
[108]Cf. Giusto, Lera, Morabito, Atzori(2010).P.5
[109]Cf. Demirer, Aydin, celik (2017), p.3
[110]Cf. Demirer, Aydin, celik (2017), p.4
[111]Cf. Demirer, Aydin, celik (2017), p.3

2.2.6 Cyber physical systems

CPS is "integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa."[112]

Cyber-physical system is the core element of Industry 4.0. CPS represents the connection between the real world and the virtual world and is the consequence of the development and application of embedded systems and global networks such as the Internet. CPS is represented by the capability to measure physical data using sensors and affect physical processes via actuators. It is able to estimate and analysis data and interact proactively or responsively with real and virtual worlds based on this data. CPS is connected through digital networks (wired and wireless, local and global) and can use available data and services worldwide. The cyber-physical system retains a multimodal human-to-machine interface for control and communication. CPS is partially autonomous, location independent, context aware, partially automated, multifunctional, connected and distributed to its stakeholders and users.[113]

The major technological driver for the appearance of CPS is the origins of hardware and software. The technological infrastructures include embedded systems as well as high-performance sensors, actuators and communication interfaces offers the unavoidable hardware capacities.[114] Almost all of these embedded systems are at present folded "boxes", which do not provide computing ability to the outside world.[115]

Embedded systems typically have two main functional demands: 1) advanced network level to offer information response from digital architecture as well as data processing from the physical infrastructure in real-time; 2) decision making, intelligent data processing and capabilities of computing to sustain the physical infrastructure. To this end, embedded systems include sensors, actuators, RTLS technologies, controllers and network systems that data or information is converted and transmitted by each device. Additionally, data collection and data processing is able to derive

[112] Hermann, Pentek, Otto (2015), p.9.
[113]Cf. Geisberger, Broy (2012), p.27
[114]Cf. Geisberger, Broy (2012), p.20
[115]Cf. Lee (2008), p. 4

from information acquisition in the form of using computational intelligence, which is supported by learning strategies.[116]

Some attributes of the embedded systems are mentioned as follows:[117]

- Improve operational safety by identifying safety-critical conditions before their importance levels.
- With sensor or sensor-less exchanging condition monitoring.
- Use feedback loops to control and monitor.
- Systematically and targeted integration of data storage and analysis interactively and directly on the local control, in the public cloud systems or in private network.
- Flexible and reconfigurable components and machines.

Another feature that is able to be applied to describe CPS, while representing the different dimensions of these systems, is the decentralization level of their structure and their dimensional capacity. Through advanced micro-system technology, a CPS is able to be put on a single microchip consisting of many sensors and a microprocessor for data processing. A larger CPS can be built as a whole machine, and the entire machine can be part of an even larger CPS - the entire plant. An extreme performance of CPS is the distribution in a global network, for example in a globally operating firm.[118]

Geisberger and Broy describe five important dimensions of CPS, which build upon each other to increase transparency, intelligence:[119]

(1) Integration of the physical and virtual worlds;

(2) Systems of Systems with dynamically adaptive system boundaries;

(3) Autonomous systems with context-adaptive systems; Active real-time manipulate;

(4) Collaborative systems with allocated and modifying control;

(5) Widespread cooperation between people and systems.

The concept of Industry 4.0 will benefit small and medium-sized enterprises. The digitization of the manufacturing sector will ensure these companies to operate in global

[116]Cf. Ustundag, Cevikcan (2018), p.8
[117]Cf. Ustundag, Cevikcan (2018), p.8
[118]Cf. Lucke,Görzig, Kacir, Volkmann, Haist, Sachsenmaier, Rentschler (2014), p. 14
[119]Cf. Geisberger,Broy (2012), p.63

markets, which is very unusual in the current model.[120] In the next chapter, the definitions and characteristics of small and medium-sized enterprises will be discussed in detail.

[120]Cf. Kagermann, Helbig, Wahlster (2013), p.35

3 Small and medium-sized enterprises

In this chapter an understanding of small and medium-sized companies (SMEs) is provided. Section 3.1 gives the official definition of SMEs. In section 3.2, the strengths and weaknesses of SMEs are discussed.

3.1 SMEs definition

In most economies around the world small and medium-sized enterprises (SMEs) are a growing and dynamic sector. SMEs are often seen as a homogenous group, particularly by the government. Nevertheless, this hides the big differences in terms of dimension, structure and objective that belong to this sector. To define the SME sector, especially small enterprises, is quite difficult because there are differences in what is adequate to define as "small" in various industries. The primary criteria dominate to determine the SMEs sector refers to the number of employees, the turnover and the total balance.[121] The definition from the European Commission for micro-, small- and medium-sized enterprises is shown in Table 1.

Company category	Employees	Turnover	Balance sheet total
Medium-sized	<250	<=€ 50 million	<=€ 43 million
Small	<50	<= € 10 million	<=€ 10 million
Micro	<10	<= € 2 million	<=€ 2 million

Table 1: Definition of SMEs in EU.[122]

With the help of the thresholds for the following three criteria, an enterprise is able to determine whether it is a micro, small or medium-sized enterprise by comparing its data:[123]

- A micro-enterprise is defined as a company that employs less than 10 persons and has an annual turnover or annual balance sheet total of not more than EUR 2 million.

[121]Cf. Burns (2016), p.12
[122]Adapted from European Commission
[123]Cf. User guide to the SME definition

- A Small-enterprise is defined as a company that employs less than 50 persons and has an annual turnover or annual balance sheet total of not more than EUR 10 million.
- A Medium-sized enterprise is defined as a company that employs less than 250 persons and either has an annual turnover of not more than EUR 50 million, or an annual balance sheet that not more than EUR 43 million.

The Organization for Economic Cooperation and Development (OECD) defines SMEs uses the numbers of employees with hardly different criteria: micro-enterprises have less than 20 employees, small businesses have employees between the number of 20 and 99, and medium-enterprises have 100 to 299 employees. At the same time, the US defines all enterprises with less than 500 employees as small and medium-sized enterprises. For most countries, where the large number of enterprises employs less than 250 persons, the definition of the United States is too large. In addition, the organizational features of companies with 500 employees often resemble to large companies with formal structures, which is a beneficial definition for research into SMEs.[124] The country and the responsible institute determine the characteristics of SMEs. The core focus of this thesis is on the definition of SMEs by the European Union.

SMEs are the backbone of the global economies. In most countries, the number of SMEs as well as their share of employment increases. Almost 99.9% of EU firms are SMEs. They created an employment rate of 67.1% and a GDP or manufacturing value added of 57.6%.[125]

The following table indicates some qualitative characteristics defining SMEs compare with large companies.

Category	SMEs	Large companies
Organization	• High personalized contacts, strong personal relationship	• High formalized communication, low personal relationship
Personnel	• Lack of academicals education • Wide specialized know-	• Dominance of employees with academicals education

[124]Cf. Levy, Powell (2005), p.20
[125]Cf. Burns (2016), p.16

	ledge	• Specialization
Management	• Owner-employer • Functions linked to personalities • Delegation in limited scope	• Manager • Division of labor through subject issues • Delegation in many areas
Research development	• Following the market, rarely fundamental research • No long-term institutionalized research development department	• Product and process development, related with fundamental research • Long-term institutionalized research development department
Production	• Labor intensive • Little division of labor • Mainly universal equipment	• Capital intensive, economies of scale • High division of labor • Mainly specialized equipment
Relationships with buyer	• Unstable	• Based on permanent contracts
Sales	• Comparative position inconsistent	• Good competitive position
Financing	• Role of family funds, in the family ownership • No access to anonymous capital market, therefore only little financing possibilities	• Broadly scattered ownership structure • Access to anonymous capital market, therefore diverse financing possibilities

Table 2: Qualitative characteristics defining SMEs compare with large companies.[126]

[126] Adapted from Yon, Evans(2011), p.6

Levy and Powell suggest there are five core affects on small business:[127]

- Market: Most SMEs have high levels of market uncertainty because they often have a smaller market share and own only one or two large customers. Therefore their influence on the prices is weak. SMEs are often price-accepters. Because large companies have high market share, therefore they usually can decide the price.
- Independence: Independence indicates that SMEs are not willing to be funded or supported by larger companies. In many instances, the chief executive officers (CEO) can independently make decisions and performance of the parent company. Their activities and operations equal to independently possessed SMEs. Particularly, the CEO makes the decisions of investment.
- Personal: The owners and their attitude towards the company personify the management of a small company. The owner associates with all aspects of administrating the company. This can sometimes cause problems when the business has risen in this way that it is needed to assign decision-making.
- Flexibility: SMEs are seen as flexible and innovative organizations that can respond fast to customer and market needs. Flexibility is a key feature of SMEs and represents the capability to adjust to a changing circumstance.
- Innovation: Innovation is also seen as a key feature of SMEs. Innovation primarily refers to the ability to respond to the changing needs of customers within their niche markets within the scope of knowledge regarding current products or services. Although SMEs often do not handle costly research and development, but they are able to be more innovational than larger companies.

SMEs are often thought to be flexible, innovative and adaptive, and therefore they are better able to react on new opportunities and innovations than larger companies. However, many studies reported that SMEs are often falling behind larger enterprises regarding in adopting and using new Information and Communication Technology (ICT). As SMEs are the backbone of the European economy, this becomes a critical problem. SMEs are not just big companies with smaller scales. They have individual, unique and particular characteristics themselves. Although size is a key differentiator, the important aspects of SMEs impacting their ICT adoption also differ from

[127]Cf. Levy, Powell (2005), p.22

those of large companies. The introduction of information systems innovations in SMEs could not be considered as a miniaturized version of a larger enterprise.[128]

Nemours SMEs announce practical difficulties in introduction of ICT. SMEs tend to lack sufficient technical specialists, management and financial resources for the investment of ICT, and consciousness regarding the potential benefits of using ICT. By contrast, the main drivers of ICT introduction appear to be the apperceived benefits, organizational preparedness, and external stress.[129]

Burgess explained that the literature on small enterprise and information technology is full of the list of "barriers" that are now recognized as a successful implementation of Information Technology (IT) in small businesses. These barriers usually include:[130]

- The cost of IT;
- Lack of time to invest in the performance and maintenance of IT;
- Lack of IT skills combined with difficulty in finding useful, fair advice;
- Lack of use of external consultants and vendors;
- Short-term management views;
- Lack of awareness of the benefits that IT can offer and how to measure them;
- Lack of control processes or formal planning.

3.2 Strengths and weaknesses of SMEs

Essentially, technology is a tool that allows SMEs to operate faster, better and more efficiently. Understanding what they have done well and what they require to improve is the key to select the right technology for their business. This subsection discusses the strengths and weaknesses of SMEs.

An advantage of small businesses is that they are flexible. They are capable to retain labor relationships, serve niche markets and have low capital demands. The fact that they are under continuous pressure in their business operations can also motivate them to be creative and innovative. These factors are able to assist them to defeat the barriers mentioned in the last subsection.[131]

[128]Cf. Pucihar, Lenart, Sudzina (2010), p.58
[129]Cf. Pucihar, Lenart, Sudzina (2010), p.59
[130]Cf. Burgess (2002),P.5
[131]Cf. Burgess (2002),P.5

Strengths of SMEs

From an economic point of view, SMEs offer many benefits as following:[132]

- SMEs are able to easily adjust to changing trade patterns, requirements patterns and macroeconomic environments because of their size. Industrial flexibility is increased.
- SMEs have a rational tendency to obtain technological abilities and develop new products and processes, so they can promote to national technological evolution and competitiveness.
- SMEs are able to be an important tool to create revenue and employment, thereby promote to the economic growth and the gross domestic product and reduce unemployment.
- SMEs offer an environment in which resources and capabilities can be gathered. This can bring better economic opportunities for persons who obtain the capabilities and for the families they help to support.
- SMEs can reduce wage imbalance. This is done so mainly through increase economic involvement in the lower half of the revenue allocation.

Weaknesses of SMEs

- Limited Investment monitoring: A feature of SMEs is their non-continuous activity to investment, if the investment is fairly large compared to the size of the firm, it will threaten the existence of the firm.[133]
- Limited resources: SMEs generally lack of the financial and human resources.[134] Therefore, in the event of sudden changes, such as market and economic fluctuations, the existence of SMEs is more threatening than the existence of large companies. This is because SMEs do not just have relatively few resources to conquer restructuring measures, but they cannot get rid of competitive pressure.[135]
- Difficulties in hiring qualified employees: Given the risks outlined above, which are associated with low incomes, poor prospects for economic development and low customer conscious, it is becoming progressively hard for SMEs to hire

[132]Cf. Fisher, Reuber (2000), p.5
[133]Cf. Keuper, Brösel , Albrecht(2009), p. 58
[134]Cf. Krämer (2003), p. 8-9
[135]Cf. Kosmider (1994), p. 49-50

qualified workers in the labor market.[136] Since SMEs have only one hierarchical level and few personnel development plans, the issues of training skilled employees and trainees have risen. In addition, SMEs often cannot pay enough for professional and highly qualified personnel. Normally the consequence is that there are large amount of difficulties in finding new ability in the market.[137]

- Small Management Committee: SMEs have originally limited to only one or a few managers. All management functions are concentrated on these people, which usually lead to a high level of direct reliance on the overall business operations on these people. Therefore, management is critical to the business.[138]
- Lack of internal IT staff is being substituted by new IT procurement models, because IT staff is able to be "rented" with equipment.[139]
- Limited IT investments of infrastructure are not relevant to the physical hardware and network infrastructure ownership is no longer required to operate a business.[140]
- Limited global customer and product outreach has been replaced by economic flattening, which influence stride across branding, technology and marketing.[141]

3.3 The important criteria for SMEs

The important technologies are introduced in chapter 2. The definition, characteristics compared with global enterprises, weaknesses and strengths of SMEs are discussed in the previous subsection. Due to the characteristics of SME, not all of the technologies can be adopted in SMEs. Therefore it is important to find out the criteria for selecting suitable technologies for SMEs. Based on SMEs' characteristics, their weaknesses and strengths, the important criteria which have to be fulfilled by the technologies consist of:

1. Low investment: The cost for adoption of the technology is the most important criterion for SMEs. The technology must not require huge investment and expensive facilities. In SMEs there are limited financial resources. SMEs have only

[136]Cf. Mäder , Hirsch (2009), p. 8
[137]Cf.Kosmider (1994), p. 40
[138]Cf.Kosmider (1994), p. 39
[139]Cf. Passerini, Tarabishy, Patten (2012), p.5
[140]Cf. Passerini, Tarabishy, Patten (2012), p.5
[141]Cf. Passerini, Tarabishy, Patten (2012), p.5

family funds. They are self-financed and do not have much support from the governments.

2. Easy to implement: The technology has to be not too complicate and every employee is able to implement it after a simple training. As described above, SMEs do not have many human and financial resources. Especially they don't have many specialists.
3. Flexible production: The technology need to be more flexible. SMEs usually produce their products in small batches. They cannot have mass production and make use of economies of scale, but they are flexible enough in production.
4. Individual customer satisfaction: The technology can produce product to fulfill individual customer satisfaction. They also can produce customized products according to the customers' requirements.
5. Cost-effective implementation: It is possible to increase effectiveness by applying the technology.
6. Maintenance: This criterion evaluates whether the technology is easy and cheap to maintain.

In the next chapter the technologies that mentioned in the previous chapter will be evaluated with scoring model.

4 Selection of technologies with scoring model

This chapter discusses the selection of the suitable technologies for SMEs with scoring model. At first the scoring model will be introduced, and in subsection 4.2 the evaluation of the technologies will be discussed.

4.1 Scoring model

A scoring model contains a set of corresponding criteria that the decision maker expects to consider when choosing a project from an alternative list. Then the decision maker evaluates each criterion, usually on a digital dimension with anchor phrases. At last, multiply those scores through weight and add them to all the criteria, a score that represents the value of the project will be produced. The project that gets the higher value wins. The scoring model is able to be designed especially for any specific alternative condition.[142]

Although this method can be applied for any type of project, they are particularly helpful in the earlier stages of the project lifecycle when making decisions for major project selection. The value of the scoring model is that it is able to be customized to suit the decision circumstances, considering several objectives and criteria, both judgmental and objectivity, which are considered significant for the decision.[143]

3 types of scoring model are introduced as follow:[144]

- Unweighted factor scoring model: The score for each criterion is different in this model, but individual criterion has the identical importance. To rate the criteria, a five-point scale is often used, where 5 is very good, 4 is good, 3 is fair, 2 is poor, 1 is very poor. This is according to the nature of the situation. After sum all scores up, the criterion with the highest score will be chosen, and will be accepted as the company's decision.
- Weighted factor scoring model: Every individual criterion is of different levels of importance in this model. This model consists of a factor weighting component. This component will be allocated a value between 0 and 1. The weight means that proportions of this criteria and summation of the weight is 1. In order to get

[142]Cf. Milosevic (2003), P.22
[143]Cf. Milosevic (2003), P.29
[144]Cf. Verzuh (2003), p.72

the answer, each weight is multiplied by the corresponding score. At the end the sum of the multiplied lines is the final answer.

- Unweighted 0-1 model: There are various criteria to be evaluated in this model. Every individual criterion is scored as a 0 or 1. The major disadvantages are that it supposes every criterion is considered as of identical importance and there is no gradation.

At the end of this chapter, the unweighted factor scoring model will be used to evaluate the technologies.

4.2 Evaluation of the technologies

In this subsection the technologies will be evaluated according to the different criteria mentioned in the previous chapter.

4.2.1 Data analysis

Big data and analytics

➢ **Low investment**

Most of the technologies that are categorized as "big data" are not new. Instead, it is the capability to package these technologies in the way that are accessible to organizations, in the way that have until lately been restricted by resources, budgets, and technique constraints, which are classical of smaller enterprises. The main reason of making the big data concept so attractive is that emerging technologies can achieve a wide range of analytics ability with a comparatively low barrier to entry.[145]

➢ **Easy to implement**

Classic business analysis tools have been changed very transparent and accessible. But then big data analytics tools are very complex, programming-intensive, and require applying multiple capabilities.[146] To support big data, an appropriate environment must be established. Consequently, good design principles must be kept in mind that might have one chance to handle storage, applications, or report analytics. Some consideration must be contained to set up software, hardware, administra-

[145]Cf. Loshin (2013), p.6
[146]Cf. Kudyba (2014), p.53

tion software, operational software, and explicit interfaces of application programming.[147]

- **Flexible production**

Big data and analytics can collect and fully evaluate data from multiple sources and customers in order to support real-time decision making and enhance equipment services.[148] Analyze data from sensors, which observe the operation of machines in manufacturing industry in order to earlier predict and replace component failures to prevent considerable down time.[149] Big data and analytics offer historical, forecast, and specification analysis can deeply understand what actually happens in a machine or process. Combining these new self-awareness and self-prediction components, analytics can supply precise predictive maintenance programs for assets and machines enable them to maintain productive services over a longer period of time, and reduce the cost of inefficiencies and unnecessary maintenance.[150]

- **Individual customer satisfaction**

Big Data offers chances to analyze customer behavior structures based on internal and external customer actions.[151] Every characteristics of the customers' access on their online website are saved by online retailers. Customer's visits must be analyzed within a rational amount of time (e.g., real-time) to suggest alike and related goods regarding the goods a customer is currently viewing. This assists companies to fascinate new customers and maintain the advantage over their competitors.[152]

- **Cost-effective implementation**

Big data analytics attractive to all kinds of companies are caused by the changes in the environment, while the market conditions allow them realistic.[153] Business drivers are regarding flexibility in utilization and analysis of collections of datasets and flows to create value: increasing sales, reducing costs, improving customer experiences, reducing risks, and increasing productivity.[154]

---

[147]Cf. Doraikannan, Selvaraj (2019), p.49
[148]Cf. Bahrin, Othman, Azli, Talib (2016), p.139
[149]Cf. Pusala, Salehi, Katukuri, Xie, Raghavan (2016), p.14
[150]Cf. Gilchrist(2016), p.5
[151]Cf. Pusala, Salehi, Katukuri, Xie, Raghavan (2016), p.14
[152]Cf. Pusala, Salehi, Katukuri, Xie, Raghavan (2016), p.13
[153]Cf. Loshin (2013), p.8
[154]Cf. Loshin (2013), p.4

Cloud computing

- **Low investment**

Cloud-based companies typically pay just for the resources they use up. Consequently, companies that used to depend on expensive data centers to store their processing resources could now transition their cost and maintenance efforts to cloud-based, scalable, pay-as-you-go options.[155]

- **Easy to implement**

Cloud computing is a concept of web-based computers, services and resources that help system designers to execute complicated web-based systems. Typically, developers consider cloud-based resources as virtual resources. This indicates that if a system or solving method requires more resources for example disk space or server, it is easy to add resources when needed and are usually transparent to cloud-based applications. Cloud-based solutions can often be enlarged or reduced in size to meet user requirements.[156]

- **Flexible production**

Cloud computing solves the problem according to remote data storage, such as the cost and volume needed to store large amounts of data sets. Additionally, cloud providers provide analytics tools that can handle large amounts of information.[157] With increasing technology performance, machine data and functions are increasingly exploited to the cloud, allowing more data-driven services for production systems. More works in connection with production in Industry 4.0 needs increased data exchange across locations and enterprise boundaries.[158] Because of the advantages such as more flexibility, widespread high-capacity network availability, cost-effective computers and storage devices, and service-oriented architecture, cloud computing will be the most prospective fundamental concept that is able to be borrowed in the design and manufacturing sectors.[159]

- **Individual customer satisfaction**

Customers can partially access to a small part of the cloud. Sales orders and detailed demands are noted in the cloud. Since the material is always tagged, the sta-

---

[155]Cf. Jamsa (2013), p.15
[156]Cf. Jamsa (2013), p.15
[157]Cf. Gilchrist (2016), p.5
[158]Cf. Bahrin, Othman, Azli, Talib (2016), p.139
[159]Cf. Thames, Schaefer (2017), p.10

tus of the goods can be seen and tracked at any time. Therefore, the customers know about the degree of fulfillment and the delivery performance of their ordered goods. More importantly, customers can even connect to the cloud after the ownership of the company has been transferred to them.[160]

- **Cost-effective implementation**

The result of the cloud-computing model enables organizations to collect and analyze more data than ever before. It will reduce storage, compute and network costs.[161]

- **Maintenance**

The key benefit of cloud computing is that customer does not have to pay for the infrastructure, installation, and work required to manage this infrastructure and maintain it.[162]

4.2.2 Identification

Sensors and actuators

- **Low investment**

In recent years, the cost and size of sensor technology has dropped significantly. This makes the tools of machines, processes and even human both financially and technically practical.[163]

- **Easy to implement**

Sensor networks are limited by a distinct series of resources, for example restricted network communication bandwidth and limited on-board battery power. In a classic sensor network, every sensor node manipulates unrestrictedly and has a microprocessor and a small volume of memory for scheduling of task and processing of signal. Every node is also deployed with one or more detection devices. Every sensor node wirelessly contacts with some other local nodes within its radio transmission scope.[164]

---

[160]Cf. Zhang, Li, Wang, Cheng(2017), P.144
[161]Cf. Gilchrist (2016), p.6
[162]Cf. Jadeja, Modi (2012), p.1
[163]Cf. Gilchrist (2016), p.4
[164]Cf. Zhao, Guibas (2009), p,.247

- **Flexible production**

Sensors can be self-aware and is able to forecast the rest of their useful life. Consequently, the sensor can generate data that is not only accurate but also predictable. Machine sensors from the controller are able to be self-aware, self-predict and self-compare. For instance, they are able to compare their current structures and condition settings with pre-configured best data and thresholds. This offers a self-diagnostics.[165] With intelligent sensors and parts, all relevant machines throughout the whole supply chain process and production line can be monitored.[166]

- **Individual customer satisfaction**

In contrast to recent information services, such as information on the Internet, because it is too common, may become outdated or useless, the sensor network guarantees to join end users straightly to sensor measurements and offer information that is accurate localized in time or place corresponding to the user's requirements.[167]

- **Cost-effective implementation**

Sensor networks are created to collect information from the physical world.[168] Sensor technology increases operating efficiency, such as faster, more precise, and more cost-effective inventory management.[169]

- **Maintenance**

Wireless sensor networks require new computations, algorithms and protocols, as well as design methods and tools that sustain distributed signal processing, information storage and management, networking and application development.[170]

QR code

- **Low investment**

Most of the QR code generation tools and readers do not need to pay.[171] QR codes are inexpensive to create and easy to implement. They become the preferred medium in poster advertising to attract potential customers.[172] The QR code provides unrestricted global access to create a commercial QR code with no limitation or free.

[165]Cf. Gilchrist (2016), p.4
[166]Cf. Neef (2015), p.97
[167]Cf. Zhao, Guibas (2009), p,.247
[168]Cf. Zhao, Guibas (2009), p,.248
[169]Cf. Gilchrist (2016), p.24
[170]Cf. Zhao, Guibas (2009), p,.247
[171]Cf. Price (2013), p.1
[172]Cf. Krombholz, Frühwirt, Kieseberg, Kapsalis, Huber, Weippl (2014), p.79

They can be generated with free software, which is usually pre-installed on smart phones, and can be copied with traditional printers.[173]

- **Easy to implement**

It is very easy to use QR code creation tools and readers, so the time needed indicating their usage in a learning condition is very short.[174] They were originally created to track automotive components within the manufacturing processes. They are already suitable for many applications cases today. The QR code can be read from various angles, and the data can be successfully translated even though the code is covered partly or broken.[175]

- **Flexible production**

QR codes and the barcodes are alike used to track the retail inventory, besides QR codes are able to share more information. Actually, the QR code can contain thousands of alphanumeric characters, enabling it a helpful tool for any companies.[176] QR codes can be incorporated into a wider range of production and consumption systems: the Kanban culture. It was generated in the late 1940s and is a just-in-time inventory system that keeps high production levels and reduces waste. The concentration is on real consumption instead of forecast consumption.[177]

- **Individual customer satisfaction**

QR codes are able to generate customer loyalty and support the maintenance of customer relationships. Direct sales can also be created.[178] With QR codes, customers can not only scan advertising and retrieve information, but companies also can scan customers to access customer-individual information such as position and previous purchases behaviors.[179]

- **Cost-effective implementation**

QR Code is a dynamic, powerful and innovational instrument, which can assist the digital services in digital libraries in a cost-effective way.[180]

---

[173]Cf. Brabazon, Winter, Gandy (2014), p.7
[174]Cf. Price (2013), p.1
[175]Cf. Krombholz, Frühwirt, Kieseberg, Kapsalis, Huber, Weippl (2014), p.79
[176] Cf. Price (2013), p.1
[177]Cf. Brabazon, Winter, Gandy (2014), p.7
[178]Cf. Simoes, Barbosa, Filipe (2019), p.102
[179]Cf. Simoes, Barbosa, Filipe (2019), p.102; Gönül, Qui, Zhou (2015).
[180]Cf. Singh (2016), p.969

- **Maintenance**

The cost of creating a QR code is very low and maintenance costs are less expensive than other technologies. The software used to create the code is available online and above all free of charge.[181]

Radio frequency identification (RFID)

- **Low investment**

In contrast to cheap barcode technology, RFID technology is much more expensive. Due to the need to produce larger memory chips, the various data that must be encoded in the RFID tags results in more expensive products. This rises the time that is needed to read and transfer data.[182] The costs of RFID system include tags, printers, readers, research and development, and infrastructure that rely on the number of sites, the environmental conditions at each site, training, current system changes, execution, change management, and additional costs of employees. Therefore, companies who consider an RFID application must be especially active in analyzing their benefits and costs.[183]

- **Easy to implement**

With RFID, all parts of the production line can be remotely tracked and controlled. Every RFID tag for raw materials and spare parts is distinct, including data of production such as date, serial number and size. The RFID scanner on the branches of conveyor belts or machines reads the data and problem correlated with instructions to logistics systems or robots. At the same time, the data of production is transmitted to the cloud terminal so that the administration level responds fast to each position. This also sustains convenient inventory, quality control and optimized delivery in the warehouse section.[184] Products with RFID tags can even be read if the products are not straightly reachable to the reader. The farthest distance for RFID readers to read data is 10 meters. RFID tags are very counteractive to physical destroy. The reading speed is very high so that hundreds of tags can be read in one second. Necessary information can be added to the relevant species of subsequent RFID tags.[185]

---

[181] Cf. Medic, Pavlovic (2014), p.166-174
[182] Cf. Hozdic (2015), p.33
[183] Cf. Fish, Forrest (2008), P.20
[184] https://www.hopelandrfid.com/industry-4-0-smart-manufacturing_n40
[185] Cf. Hozdic (2015), p.33

- **Flexible production**

For the purpose of achieving intelligent manufacturing, the key link is flexible production, which is characterized by the emphasis on customer customization and individualization. RFID identification technology connects raw materials, factories, distribution and customers in the MES and ERP systems of the company. The customer simply has to send an order, the factory automatically purchases the raw materials correlate with the needs of the customer, arranges the production and then sends the products directly to the customer.[186]

This is considered to be a key technology of cross-industry because objects can take along their own information, making the objects with no contact and automatically recognizable and localizable. However, the information in the RFID tag not only enables the pure recognition of the object, but also allows the object "knows" where to go and how to get there from the beginning.[187]

- **Individual customer satisfaction**

Customer service is improved because the system offers information about where and how much the customer wants the product. It will enhance understanding of customer needs and following prediction and volume planning, and increased customer relationships.[188]

- **Cost-effective implementation**

The entire supply chain will take advantages from the overall exchange of inventory information. Because repeat steps can be removed, operations business processes can be enhanced. Transport management is improved as additional information leads to more efficient transportation of goods through the supply chain. The warehouse business is improved because the extra information can be used to locate goods and cross-docking. Ideally, sufficient execution across the entire supply chain will reduce supply chain costs and variability.[189]

[186]https://www.hopelandrfid.com/industry-4-0-smart-manufacturing_n40
[187]Cf. Bullinger, ten Hompel(2007), p.21
[188]Cf. Fish, Forrest (2008), P.16
[189]Cf. Fish, Forrest (2008), P.17

4.2.3 Workplace

Machine-to-machine (M2M) communication

- **Low investment**

The M2M device is able to be stationary (e.g., a machine in a plant) or mobile (e.g., a device of fleet management in a lorry). The M2M device and the infrastructure are connected to the access network via a wired or wireless connection.[190] M2M communication includes a huge sensor network with extensive sensor data from many sensors, devices, meters and electric vehicles. Predictive analytics and data mining are important for effective and optimized implementation of such networks.[191]

- **Easy to implement**

The advent of cost-effective sensor and actuator nodes (e.g., RFID tags), which are able to wireless communicate over standardized interfaces and protocols, and increased computing ability enable the development of a great amount of M2M communication applications. These M2M applications are suggested in the basis of the feasibility for a great amount of M2M devices to connect with each other and to transmit their perceived information from the environment in which a variety of applications are allocated.[192]

- **Flexible production**

Industrial M2M communication will improve the intelligence of the control systems to enhance the automation of industrial factories by sharing and collecting information between actuator, sensors and RFID tags in the M2M communication that relates to the products. These M2M devices are able to observe vibrations in industrial machines and indicate warning signals, or even stop the entire production process when a certain threshold is exceeded.[193]

- **Individual customer satisfaction**

M2M is able to improve quality. For example, many washing machine manufacturers can better observe the utilization of their on-site machines to concentrate their investment on the parts that are most likely to broken and possibly reduce costs by not

[190]Cf. Ghavimi (2015), p.526
[191]Cf. Ghavimi (2015), p.538
[192]Cf. Ghavimi (2015), p.538
[193]Cf. Ghavimi (2015), p.540

over undertaking other aspects of the machine. It can also increase customer satisfaction.[194]

- **Cost-effective implementation**

M2M is able to reduce costs and allow more effective operations. As the M2M solution replaces Manpower, the processes are automated and the related labor costs are reduced. In fleet management, the M2M solution enables real-time optimization of the transportation lorry route, which not only reduces the related labor costs, but also reduces entire fleet costs, including costs associated with vehicle.[195]

- **Maintenance**

If the machine fails, the machine can be informed via the mobile terminal to the maintenance engineer and will receive information about the cause of the failure. Using this information can significantly speed up maintenance and reduce machine downtime.[196]

Autonomous robots

- **Low investment**

The cost is the driver as well as the barrier to the performance of robotics technology. Buying a robot is usually expensive.[197] The robot requires sensors in order to gain information of outside world and to monitor the internal conditions. Robots need sensors both to receive information from the outside world and to monitor their internal environment.[198] The robot also needs actuators that allow it to influence the environments.[199] They are the first procedure to the automation in production. Because robots require to be invested separately, SMEs may consider buying them based on their important operations.[200]

- **Easy to implement**

Robots become more flexible, autonomous and collaborative. They will communicate with each other, operate side-by-side with people safely and learn from them.[201] Robots can complete repetitive missions more efficiently than people. The

[194] Cf. Morrish (2015), p.348
[195] Cf. Morrish (2015), p.348
[196] Cf. Braun (2017), p.7
[197] Cf. Global trends 2030 (2012), P.91
[198] Cf. Bekey (2005),p.10
[199] Cf. Bekey (2005),p.12
[200] Cf. Antosz, Stadnicka(2018), P.481
[201] Cf. Bahrin, Othman, Azli, Talib (2016), p.139

robot must be installed as a part of the manufacturing system. [202] The implementation of the robot requires improved skills.[203]

- **Flexible production**

Robots have natural flexibility compared to other forms of automation. It is able to be recalled and operated in seconds, in case an operation is programmed into the robots. Thus it is very quickly to changeover and downtime can be also minimized. The robot system is able to deal with variety of the identical product or different products, offering the opportunity for small lot size. Devices around the robot may have limitations for example fixtures or grippers, but these limitations can be conquered by careful design and good concepts. However, it should be known that robots are not as flexible as human operators.[204]

- **Individual customer satisfaction**

Robots will always produce high quality products that are properly set up and provide constant input raw materials. The robot is flexible and once the process is programmed into the robot, it can be recalled and executed in seconds. The robot system can process variants of the same product or even different products, thus offering opportunities for small lot sizes. This can also meet the needs of customers.[205]

- **Cost-effective implementation**

The saving of labor costs is an important advantage in the implementation of robots. Other benefits include lower operating costs, increased product quality and conformity, reduced capital costs, increased quality of work for employee, increased production output rate, increased production flexibility, and reduced material waste, improved health and safety at work and reduced labor turnover.[206]

- **Maintenance**

The maintenance of the robots needs improved technical capabilities.[207]

[202]Cf. Antosz, Stadnicka(2018), P.481
[203]Cf. Wilson (2015), p.36
[204]Cf. Wilson (2015), p.37
[205]Cf. Wilson (2015), p.36
[206]Cf. Wilson (2015), p.35-40
[207]Cf. Wilson (2015), p.36

Additive manufacturing (3D printing)

- **Low investment**

As mentioned in the previous chapter, 3D printing has been widely applied by product designers and for some applications of manufacturing. The property of additive manufacturing machine is increasing, the scope of materials is enlarging and prices for both materials and printers are rapidly decreasing.[208]

- **Easy to implement**

The fundamental principle of AM is that models, originally created with the help of the three-dimensional computer-aided design (3D CAD) system, are able to be manufactured directly without the requirement for planning the process. The AM technology undoubtedly simplifies the creation of complex 3D items directly from CAD data. Other manufacturing processes need cautious and detailed analysis of part geometry to define the order in which various characteristics can be made, which tools and processes have to be applied, and what additional fixtures to finish the part may be needed. In contrast to this, AM requires only a few fundamental measures and a little knowledge about how the AM machine works and the materials that are needed to build the part.[209]

- **Flexible production**

3D printing is flexible and products can be customized with it. It is possible to reduce the division of labor, take over the requirement of assembly process, production of discarded bulk materials and the complete elimination of transportation and energy from production to distribution and deliver to consumer.[210] Additive manufacturing methods are widely employed in Industry 4.0 to manufacture small lot size of customized products that provide structural advantages, for example lightweight and complex designs. Decentralized and high-performance additive manufacturing systems will decrease transport distance and inventory.[211]

[208]Cf. Kocovic (2017), p.67
[209]Cf. Gibson, Rosen, Stucker (2015), p.2
[210]Cf. Birtchnell, Urry (2016), p.7
[211]Cf. Bahrin, Othman, Azli, Talib (2016), p.139

- **Individual customer satisfaction**

From the view of the application, AM provides a high level of personalization and customization with little influence on the complexity of manufacturing and cost because the AM process does not include any tools and related cost components.[212]

- **Cost-effective implementation**

In the test and small batch production environments, material waste, materials related time and costs, and stock levels are considerably reduced. Additionally, it is possible to produce parts with complex geometrical shapes, compositionally heterogeneous and customized parts.[213]

- **Maintenance**

As a mechanical machine, 3D printers require periodical maintenance. It includes cleaning or replacing the surface of the print, cleaning the drive gear or nozzle of the extruder, and lubricating the slider or rod and lead screw of the printer.[214]

4.2.4 Transportation

Automated guided vehicle system (AGVs)

- **Low investment**

The AGV has electronically guided and non-contact sensors. A standard PC can control it. Magnetic and laser navigation are the typical "free" navigation technologies. WLAN are accepted as a way of data transfer. [215] The AGV cannot have the identical throughput compared as the conveyor, does not offer buffering and are further costly. Wall-mounted targets and laser scanners or an integrated GPS system are used to identify their position. [216]

- **Easy to implement**

However, to ensure the implementation of a range of standards and conditions, normal operation of the AGV system is required. It is mainly all with respect to well-planned routes. The route of every AGV system must be designed according to the entire layout.[217] Another essential condition for the appropriate implementation of an

---

[212] Cf. Yang, Hsu, Baughman, Godfrey, Medina, Menon, Wiener (2017), p.6
[213] Cf. Yang, Hsu, Baughman, Godfrey, Medina, Menon, Wiener (2017), p.6
[214] Cf. Evans (2012), p.281
[215] Cf. Ullrich (2015), p.10
[216] Cf. Wilson (2015), p.42
[217] Cf. Hou,Liu, Shi,Zheng(2016), p.263-268

AGV is the introduction of a control and supplementary information system. [218] Within the operation, various techniques such as RFID tags are possible to be used.[219]

- **Flexible production**

In intra-logistics, AGVs are often applied to realize flexibility. In modern manufacturing factories, AGVs are more and more used for material transfer in production lines. The goal is to increase material transfer efficiency and improve production.[220] With AGVs nearly every load can be transported. The AGV can basically be used for all transport operations of pallets, containers, bales, sacks or similar items. The handling of the goods has changed from the initial one-way transport to the multi-dimensional transport since the vehicles can now transport goods almost anywhere in the warehouse or at the factory. Additionally, they can place the goods as needed and carry out ergonomic assembly work. Complex traffic networks are made by many vehicles with cross-connections and more and more load transfer stations.[221] However, the speed of AGVs is not too fast, the size and weight of product that can be managed are restricted.[222]

- **Individual customer satisfaction**

A good material handling system can handle material in a controlled way, and therefore decreases damage of products. Product quality is increased because less damage in the process. The damage of using AGVs is decreased because they travel on a route which is predetermined, and they contain safety characteristics that make it almost impossible to crash with the shelf and other barriers. Therefore, it can reduce waste, reduce maintenance and increase customer satisfaction.[223]

- **Cost-effective implementation**

AGVs improve productivity, flexibility and product quality.[224] In addition, the routing is able to be changed fast to accelerate new or changed processes and at comparatively low cost. Additional labor (reduction in line changeover) and inventory (less process waiting time) costs can be reduced.[225]

---

[218] Cf. Girault, Loiseau,Roux (2016), p.583-610
[219] Cf. Lu, Xu, Zhong (2016), p.1333-1342
[220] Cf. Schwarz, Sauer (2012), p.271
[221] Cf. Ullrich (2015), p.14
[222] Cf. Wilson (2015), p.42
[223] Cf. Shang (1999), p. 243
[224] Cf. Shang (1999), p. 243
[225] Cf. Mitchell (1998), p.2-5

➢ **Maintenance**

The availability of the system can be ensured by executing proper maintenance, which can be major or minor repaired, or even replaced by broken parts take place. In general, preventive maintenance is routinely performed in spite of the actual condition of the AGVs.[226]

Conveyor system

➢ **Low investment**

The potential cost of the actual equipment and related electrical controls are as follows:[227]

- Electrical and Mechanical installation.
- Information technology programming for any interface with a warehouse management system (WMS) or host enterprise resource planning (ERP) system.
- Training of the employees.
- Regular maintenance and professional training for maintenance personnel.
- Cost of spare parts and stocking spare parts on site.
- Contracts of maintenance.

If the conveyor contains only a few 3 meter roller conveyors, the whole list can be almost ignored. However, since the system increases in size, more and more of this list will play a role.[228] In this thesis the conveyor system is considered very large system. The company must make sure that the building is sufficient robust to carry the extra weight of the conveyor system. The floor has to be sufficient robust to carry the extra load and the roof structure must be sufficient robust to sustain the ceiling suspension.[229]

➢ **Easy to implement**

The conveyor control system includes a hierarchical structure of a computer system. Conveyors can be created to carry out a number of functions, such as moving, tracking, and scanning, merging, and buffering, segmenting, and sorting products

[226]Cf. Nakagawa (2005)
[227]Cf. McGuire (2009), p.2
[228]Cf. McGuire (2009), p.2
[229]Cf. McGuire (2009), p.3

with proper hardware, software, and communication networks.[230] It is extremely suggested to participate in the services of structural engineers or architects.[231]

- **Flexible production**

Conveyor systems are not as flexible as the AGVs, but with frequent transport tasks, the conveyor system is still an attractive method of resolving work transmit issues. Due to their mechanical simplicity, conveyors are often very reliable and have been designed to transfer loads very efficiently and flexibly.[232]

- **Individual customer satisfaction**

The flexibility of the conveyor system and the high throughput increase customer satisfaction. [233]

- **Cost-effective implementation**

The savings related to the new conveyor system is able to be tangible or intangible. Tangible savings are the advantages of easy identification and quantification. These include saving direct labor costs, eliminating overtime hours, reducing downtime of production, reducing maintenance costs, and reducing wastes. The residual value of the new system at the end of its lifetime is as well consists of the cash inflow. Intangible savings include increased safety, improved flexibility or advanced ergonomics.[234]

- **Maintenance**

The conveyor system is more complex than other systems. Therefore, failures are easy to occur and need more maintenance.[235]

4.2.5 Internet of Things (IoT)

- **Low investment**

The Internet of Things contains an enormous network of billions of networked objects.[236] In order to establish such an intelligent environment, technologies that connect the virtual world with the physical world are needed.[237] In order to execute this

[230]Cf. Mitchell (1998), p.9-20
[231]Cf. McGuire (2009), p.3
[232]Cf. Greenwood (1988), p.122
[233]Cf. Mitchell (1998), p.9-23
[234]Cf. Mitchell (1998), p.9-23
[235]Cf. Shang (1999), p. 243
[236]Cf. Andelfinger, Hänisch (2015), p.9
[237]Cf. Bullinger, ten Hompel(2007), p.21

process, every single object has a technology, for example RFID.[238] Additionally, there are sensors and actuators on the physical objects, they are so-called embedded systems, and they make sure that the objects interconnected to each other through the Internet. The purpose of the sensor is to become aware of the physical world so as to collect and process data. Actuators are applied to control the physical world, for example production processes.[239] IoT also associated with big data, identification technology and cloud computing.[240]

- **Easy to implement**

The Internet of Things indicates intelligent objects that create information based on specific technologies and exchange that information over the Internet so that they can develop optimal solutions. Therefore, machines, devices, systems, and products have the capabilities to network that allow them to interconnect to each other and share information without human intervention.[241]

- **Flexible production**

The Internet of Things has two functions through the integration of industry. When the Internet of Things is used in industry, products have subjective data on production and can share them one another. By collaborating and communicating with other physical objects, they can control the production process. On the other hand, integrating production facilities into the Internet of Things allows appropriate monitoring and controlling of production-related data as well as the planning and control of production processes.[242]

- **Individual customer satisfaction**

IoT equipments and machines with embedded sensors and actuators process a large number of data and transfer it to analysis tools and business intelligence to help people making decisions. With the help of these data business problems are identified and solved, for example the changes in customer activities and market conditions, to improve customer satisfaction and offer value-added services to customers.[243]

---

[238] Cf. Madhura, Kantilal (2014), p.658-659
[239] Cf. Bundesministerium für Bildung und Forschung (2015), p. 2
[240] Cf. Demirer, Aydin, Celik (2017), p.5
[241] Cf. Jeschke, Brecher, Meisen, Özdemir, Eschert (2016), p. 3
[242] Cf. Schöning, Dorchain(2014), p. 544
[243] Cf. Lee, Lee (2015), p.431-440

- **Cost-effective implementation**

IoT technology in industries can determine the analysis of production speed and transfer acquired production demand information through existing connections, so that productivity can be adjusted based on current conditions. [244] By using the Internet of Things in the industry, competitive advantages can be achieved, such as increasing efficiency, reducing costs, improving customer loyalty and developing new business models. [245]

- **Maintenance**

The basic IoT technologies are software, networks, and algorithms, as well as hardware and data processing. The network is the pillar of the Internet of Things. It indicates the individually recognizable objects and their virtual expression in the structure in Internet style. All this must be maintained.[246]

4.2.6 Cyber physical system

- **Low investment**

CPS is considered the most essential core technology of the Industrial Internet.[247] Therefore, CPS is described as an embedded system connected to sensors and actuators through a communication network. With the help of sensors, physical data related to value-added processes are collected and provided for Internet services. The actuators are used to control physical processes. Internet services are needed to execute this process.[248] At this time, the Internet of Things is mentioned. Additionally, machines and products with embedded systems based on the Internet of Things are networked with people.[249]

- **Easy to implement**

A cyber-physical system is made by networking physical processes with a large amount of embedded systems such as sensors and actuators with digital services that are connected to global network to establish a direct connection between the physical world and virtual world.[250] The CPS can be put on a single microchip, including diverse sensors and a microprocessor for data processing. A larger CPS is able to

[244]Cf. Demirer, Aydin, Celik (2017), p.6
[245]Cf. Mattern, Flörkemeier (2010), p. 4-6
[246]Cf. Lee, Lee (2015), p.431-440
[247]Cf. Brühl (2015), p .68-69
[248]Cf. Fraunhofer IPA, 2016
[249]Cf. Brühl (2015), p .68
[250]Cf. Broy (2010), p.17

be built as an entire machine, and the entire machine can then be a part of an even larger CPS - the entire plant. An extreme performance of CPS is its distribution in a global network, for example in a globally operating enterprise.[251]

- **Flexible production**

This networking concept can be established in the production systems of factories and companies. Embedded production systems are on the one hand vertically networked with operation processes in companies and factories and on the other hand, they are connected horizontally with allocated value creation networks - from order to deliver the goods.[252] Resource efficiency and flexibility in operation, transportation, and warehouse systems can be improved through the use of physical network systems, which allow automatic machine-to-machine communication.[253]

- **Individual customer satisfaction**

CPS must be designed to meet the requirements of its customers in order to maximize their potential. CPS has several functions. To put it simply, they can perform common functions, such as finding suitable services on the Internet, and application-specific functions for example optimization of the route in a logistics network. [254] Cyber-physical systems are very important in industrial production to meet customer needs. The structured production system will enable them to react to nearly any market changes in real-time and supply chain with the help of cyber-physical systems, which collaborate with the super-flexibility, even outside the enterprise. Not only does this enable rapid production in regarding to meet the specific demands of individual customers, it also optimizes the company's internal production processes through a network of worldwide collaborations. [255]

- **Cost-effective implementation**

Advanced systems will turn into adaptable, evolutionary and self-organized production systems. The savings and innovation potential in these production facilities is enormous.[256]

[251]Cf. Lucke, Görzig, Kacir, Volkmann, Haist, Sachsenmaier, Rentschler (2014), p.14
[252]Cf. Braun (2017), p.5
[253]Cf. Braun (2017), p.1
[254]Cf. Geisberger, Broy (2012), p.27
[255]Cf. Hozdic(2015), p.34
[256]Cf. Hozdic(2015), p.34

➢ **Maintenance**

Cyber-physical and embedded systems have to be reliable and have a variety of styles and aspects. A major aspect is the maintainability, considering that the system might breakdown, and when they breakdown, it should be have the potential to fix these systems and do not take much time. [257]

According to the evaluation described above, in table 3 the technologies are arranged with the unweighted factor scoring model. As introduced in the previous subsection, assume that the criteria have the identical importance.

Criterion / Technology	Low invest-ment	Easy to implement	Flexible production	Individual customer satisfaction	Cost-effective Implementation	Maintenance	Total
Big Data and analytics	4	5	5	5	5	5	29
Cloud compu-ting	4	5	5	5	5	5	29
Sensors and actuators	5	5	5	5	5	5	30
QR code	5	5	4	4	4	5	27
RFID	4	5	5	5	5	5	29
M2M communi-cation	4	4	5	4	4	4	25
Automated robots	3	3	5	5	4	3	23
Additive manu-facturing	3	4	5	5	4	3	24
AGVs	3	3	5	5	4	3	23
Conveyor sys-tem	2	3	4	4	4	2	19
Internet of Things	4	4	5	5	5	5	28
Cyber physical system	4	4	5	5	5	4	27

Table 3: The evaluation of technologies.

[257] Cf. Guo, Zeng (2019), p.79

Rating of technologies:

- ✓ The score is 5, if the technology has the criterion and it is a very important feature for it;
- ✓ The score is 4, if the technology has the criterion and it is an important feature for it;
- ✓ The score is 3, if the technology has the criterion, but it is with constrains;
- ✓ The score is 2, if the technology has only a little of the criterion;
- ✓ The score is 1, if the technology doesn't have the criterion.

5 Conclusion

Small and medium-sized enterprises are likely to be the basis for sustainable economic growth if they get the right tools and support. Large companies are benefiting from the technologies of Industry 4.0. In the opposite, small and medium-sized enterprises are closer to the beginning. Technologies in Industry 4.0 can help small and medium-sized enterprises to stay long-term competitive and sustainable development. There are many technologies in Industry 4.0, but not all of them are suitable for small and medium-sized enterprises, because they don't have many resources such as investment, specialists and technologies. The purpose of this master thesis is to find out the technologies that suitable for small and medium-sized enterprises.

At first, some of the technologies in Industry 4.0 are introduced and classified into 6 categories. They include data analysis, identification, transportation, workplace, Internet of Things and Cyber-physical system. Data analysis contains big data analytics and cloud computing. Sensor and actuator, RFID and QR code are technologies for identification. AGVs and conveyor systems belong to transportation. At workplace the technologies M2M communication, autonomous robots and additive manufacturing are included.

Then the definition, strengths and weaknesses of small and medium-sized enterprises are discussed. These are the basis for finding the criterions; these criterions are needed for SMEs to implement technologies. These criterions include low investment; easy to implement; flexible production; individual customer satisfaction; cost-effective implementation and maintenance. Not all of the technologies that introduced in chapter 2 can be implemented in small and medium-sized enterprises. With the help of these criterions the most suitable technologies can be evaluated.

After the evaluation with scoring model the technologies are arranged in a sequence. Based on the criterions, sensor and actuator has got the highest score. Other high score technologies are cloud computing, big data and analytics, RFID, QR code, Internet of Things, Additive manufacturing, AGVs, Cyber-physical system, autonomous robotics, M2M communication. Conveyor system got the lowest score, because it need high investment, more specialists, need more space, and require more maintenance.

As conclusion of this thesis, sensor and actuator, big data and analytics, cloud computing, RFID, M2M, Internet of Things, Cyber-physical system are the foundation to realize intelligent manufacturing and smart logistics of SMEs. Additive manufacturing (3D printing), autonomous robots, AGVs are able to increase flexibility, reduce throughput time and improve resource efficiency of SMEs. Technologies in Industry 4.0 can help SMEs to increase economic efficiency, improve flexibility, reduce costs, and reduce respond time when meet changes of the marketplace and individual customer requirements, therefore improve customer satisfaction and improve the competitiveness of the company. There is not a defined framework of Industry 4.0 for SMEs. SMEs are able to adopt technologies according to their individual demands.

List of references

Abele, E.; Reinhart, G. (2011): Zukunft der Produktion. Herausforderungen, Forschungsfelder, Chancen. München: Hanser, Carl publishing house. ISBN: 978-3-446-42805-8.

Andelfinger, V.P., Hänisch, T. (2015): Internet der Dinge, Technik, trends und Geschäftsmodelle. 1. Edition. Wiesbaden: Gabler publishing house. ISBN: 978-3-658-06729-8.

Antonopoulos, N., Gillam, L. (2010): Cloud computing. Principles, systems and applications. Heidelberg: Springer publishing house. ISBN: 978-1-84996-241-4.

Antosz, K., Stadnicka, D. (2018): Possiblities of maintenance service process analyses and improvement through six sigma, lean and Industry 4.0 implementation. In: Chiabert, P., Bouras, A., Noel, F., Rios, J. (Eds.): Product lifecycle management to support Industry 4.0. Switzerland: Springer publishing house. ISBN: 978-3-030-01614-2.

Arvanitis, G., Lalos, A.S., Moustakas, K., Fakotakis, N. (2017): Real-time removing of outliers and noise in 3D point clouds applied in robotic applications. In: Ronzhin, A., Rigoll, G., Meshcheryakov, R. (Eds.): Interactive collaborative robotics. Switzerland: springer publishing house. ISBN: 978-3-319-66471-2.

Bahrin, M. A. K., Othman, M. F., Azli, N. H. N., Talib, M. F. (2016): Industry 4.0: A review on industrial automation and robotic. JunalTeknologi. 78: 6-13 (2016), 137-143.

Bandyopadhyay, S. (2018): Intelligent vehicles and materials transportation in the manufacturing sector: emerging research and opportunities. United State of America: IGI Global publishing house. ISBN: 9781522530657.

Bekey, G. A. (2005): Autonomous robots: from biological inspiration to implementation and control. London: Massachusetts Institute of Technology. ISBN: 0-262-02578-7.

Bettenhausen, K. D., Kowalewski, S. (2013): Cyber-Physical Systems.Chancen und Nutzen aus sicht der Automation. URL: <https://www.vdi.de/uploads/media/Stellungnahme_Cyber Physical_Systems.pdf> Last access: 12.02.2017.

Bildstein, A., Seidelmann, J. (2014): Industry 4.0-Readiness: Migration zur Industry 4.0-Fertigung In: Bauernhansl, T.; Hompel, M. ten; Vogel-Heuser, B. (Eds.): Industry 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration. Wiesbaden: Springer Vieweg publishing house. ISBN: 978-3-658-04682-8.

Birtchnell, T., Urry, J.(2016): A new industrial future? 3D printing and the reconfiguration of production, distribution, and consumption. New York: Routledge publishing house. ISBN: 9781315776798.

Botthof, A., Bovenschulte, M. (2011): Die AutonomikalsintegrativesTechnologieparadigam. IIT Perspektive. Berlin. URL: <file:///C:/Users/shang/Desktop/iit_perspektive_02.pdf>Last access: 10.11.2018.

Boyle, D., Höller, J., Tsiatsis, V., Mulligan, C., Karnouskos, S., Avesand, S. (2014): From machine-to-machine to the Internet of things: Introduction to a new age of intelligence. The United States of America: Elsevier publishing house. ISBN: 978-0-12-407684-6.

Brabazon, T., Winter, M., Gandy, B. (2014): Digital wine, How QR codes facilitate new markets for small wine industries. New York: Springer publishing house. ISBN: 978-981-287-059-9.

Braun, T. (2017): Chancen und Risiken von Industrie 4.0 für kleine und mittlere Unternehmen. Eine Untersuchung am Beispiel der mittelständischen Automobilzulieferer. Hamburg: Diplomica publishing house. ISBN: 978-3-96146-540-8.

Broy, M. (2010): Cyber-Physical Systems: Innovation durch softwareintensive eingebettete Systeme. Berlin: Springer publishing house. ISBN: 978-3-642-14901-6.

Brühl, V. (2015): Wirtschaft des 21. Jahrhunderts: Herausforderungen in der HightechÖkonomie. Wiesbaden: Springer Gabler publishing house. ISBN: 978-3-658-04883-9.

Bullinger, H.J., ten Hompel, M. (2007): Internet der Dinge. München: Springer publishing house. ISBN: 978-3-540-36729-1.

Bundesministerium für Bildung und Forschung. (2015): Industrie 4.0: Innovationen für die Produktion von morgen. URL:<https://www.bmbf.de/pub/Industrie_4.0.pdf.> Last access: 12.01.2019.

Buntz, B. (2017): The top 20 industrial IoT applications. IoT world today. URL:<https://www.iotworldtoday.com/2017/09/20/top-20-industrial-iot-applications/> Last access: 08.01.2019.

Burgess, S. (2002): Managing Information technology in small business: challenges and solutions. UK: Idea group publishing house. ISBN: 1-930708-35-1.

Burns, M. (2016): Deeper learning with QR codes and augmented reality: a scannable solution for your classroom. California: Corwin publishing house. ISBN: 978150631775.

Burns, P. (2016): Entrepreneurship and small business, start-up, growth and maturity. Fourth edition. UK: plagrave publishing house. ISBN: 978-1-137-43035-9.

Dasgupta, N. (2018): Practical big data analytics. Hands-on techniques to implement enterprise analytics and machine learning using Hadoop, Spark, NoSQL and R. UK: Packt Publishing Ltd. ISBN: 978-1-78355-439-3.

Demirer, V., Aydin, B., Celik, S. B. (2017): Exploring the educational potential of Internet of Things (IoT) in seamless learning. In: Information resources management association: The Internet of things: Breakthroughs in research and practice. United State of America: IGI Global publishing house. ISBN: 9781522518334.

Deutsche Telekom. URL: http://m2m.telekom.com/telekom-m2m/about-m2m/?type=0index.php%3FeID%27A%3D0. Last access 19.12.2018.

Doraikannan, S., Selvaraj, P. (2019): Big data and digital analytics. In: Simoes, D., Barbosa, B., Filipe, S. (Eds.): Smart marketing with the Internet of Things. United States of America: IGI Global publishing house. ISBN: 9781522557647.

Evans, B. (2012): Practical 3D printers: The science and art of 3D printing. 1. Edition. New York: Apress publishing house. ISBN: 978-1430243922.

European Commission (2003-05-06). "Recommendation 2003/361/EC: SME Definition". Archived from the original on 2015-02-08. Retrieved 2012-09-28.https://web.archive.org/web/20150208090338/http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/sme-definition/index_en.htm. Last access: 29-08-2018.

Fallenbeck, N., Eckert, C. (2014): IT-Sicherheit und Cloud Computing In: Bauernhansl, T.; Hompel, M. ten; Vogel-Heuser, B. (Eds.): Industry 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration. Wiesbaden: Springer Vieweg. ISBN: 978-3-658-04682-8.

Fazlollahtabar, H., Saidi-Mehrabad, M. (2015): Autonomous guided vehicles, methods and models for optimal path planning. Switzerland: Springer publishing house. ISBN: 978-3-319-14747-5.

Federal Government of Germany, Information on Industrie 4.0 URL: <www.bmwi.de/Redaktion/DE/Dossier/industrie-40.html>Last access: 04-10-2018.

Fish, L. A., Forrest, W. C. (2008): Best practices in RFID implementation. In: Blecker, T., Huang, G. Q. (Eds.): RFID in operations and supply chain management: Research and applications. Berlin: Erich Schmidt publishing house. ISBN: 978-3-503-1008-0.

Fisher, E., Reuber, R. (2000): Industrial clusters and SME promotion in developing countries. United Kingdom: Commonwealth Secretariat publishing house. ISBN: 0-85092-648-3.

Fraunhofer IAO. (2016): IT-Studie belegt Trend zum Internet der Dienste. URL:<http://www.iao.fraunhofer.de/lang-de/ueber-uns/geschaeftsfelder/informations-undkommuni- kationstechnik/593-geschaeftsmodelle-im-internet-der-dienste.html.>Last access. 10.12.2018.

Furht, B., Escalante, A. (2010): Handbook of cloud computing. New York: Springer publishing house. ISBN: 978-1-4419-6524-0.

Geisberger, E., Broy M.(2012): Agenda CPS - Integrierte Forschungsagenda Cyber-Physical Systems. Berlin Heidelberg: Springer publishing house. ISBN: 978-3-642-29099-2.

Ghavimi, F. (2015): M2M communications in 3GPP LTE/LTE-A Networks: Architechtures, service requirements, challenges, and applications. IEEE communication surveys & tutorials, VOL. 17, No. 2, Second quarter 2015.

Gibson, I., Rosen, D., Stucker, B. (2015): Additive manufacturing technologies, 3D printing, rapid prototyping, and direct digital manufacturing. 2. Edition. New York: Springer Science + Business Media publishing house. ISBN: 978-1-4939-2113-3.

Gilchrist, A. (2016): Industry 4.0: The industrial internet of things. New York: Apress publishing house. ISBN: 978-1-4842-2047-4.

Girault, J., Loiseau, J.J., Roux, O.H. (2016): On-line compositional controller synthesis for AGV, Discret. EVENT Dyn. Syst. Appl. 26 (2016), 583– 610.

Giusto, D., Lera, A., Morabito, G., Atzori, L. (2010): The Internet of Things. New York: Springer publishing house. ISBN: 978-1-4419-1673-0.

Global Trends 2030 (2012): Alternative worlds: a publication of the national intelligence council. United States of America: Government printing offices. ISBN: 978-0-16-091543-7.

Glotzbach, U. (2009): Intelligente Objekte - klein, vernetzt, sensitiv. Eine neue Technologie verändert die Gesellschaft und fordert zur Gestaltung heraus. Berlin: Springer publishing house. ISBN: 978-3-642-02217-3.

Greenwood, N. R. (1988): Implementing flexible manufacturing systems. London: Macmillan education LTD. ISBN: 978-1-349-07959-9.

Guo, S., Zeng, D. (2019): Cyber-physical systems: Architecture, security and application. Switzerland: Springer International publishing house. ISBN: 978-3-319-92564-6.

Günthner, W. A., Durchholz, J., Kraul, R., Schneider, O. (2008): Technologie für die Logistik des 21. Jahrhunderts. In: Lehrstuhl für Fördertechnik Materialfluß Logistik - Publikationen.

Hermann, M., Pentek, T., Otto, B. (2015): Design Principles for Industrie 4.0 Scenarios: A literature review. IEEE. ISBN: 978-0-7695-5670-3.

Herzog, O., Schildhauer, T. (2009): Intelligente Objekte. Berlin, Heidelberg: Springer publishing house. ISBN: 978-3-642-02220-3.

Hou, L., Liu, Z., Shi, Y., Zheng, X. (2016): Optimizing Machine Assignment and Loop Layout in Tandem AGV Workshop by Co-evolutionary Methodology, in: Shen, W., Liu, X., Yang, C., Barthes, J.P., Luo, J., Chen, L., Yong, J. (Eds.), 2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design (CSCWD), IEEE.

Hozdic, E. (2015): Smart factory for industry 4.0: A review. International Journal of Modern Manufacturing Technologies. URL: <https://www.researchgate.net/publication/282791888_Smart_factory_for_industry_40_A_review> Last access: 11.12. 2018.

Huber, W. (2016): Industrie 4.0 in der Automobilproduktion. Ein Praxisbuch. Wiesbaden: Springer Vieweg publishing house. ISBN: 978-3-658-12732-9.

Issa, A., Lucke, D., Bauernhansl, T. (2017): Mobilizing SMEs towards Industrie 4.0-enabled Smart Products: The 50th CIRP Conference on Manufacturing Systems. URL:<https://www.sciencedirect.com/science/article/pii/S2212827117306571> Last access: 15.12.2018.

Jadeja, Y., Modi, K. (2012): Cloud computing-concepts, architecture and challenges. In: International Conference on Computing, Electronics and Electrical Technologies (ICCEET). India: IEEE publishing house. ISBN: 978-1-4673-0212-8.

Jamsa, K. (2013): Cloud computing: SaaS, PaaS, IaaS, virtualization, business models, mobile, security, and more. Burlington MA: Jones & Bartlett learning publishing house. ISBN: 978-1-4496-4739-1.

Jeschke, S., Brecher C., Meisen, T., Özdemir, D., Eschert T. (2016): Industrial Internet of Things and Cyber Manufacturing Systems. URL:< https://www.researchgate.net/publication/309035201_Industrial_Internet_of_Things_and_Cyber_Manufacturing_Systems> Last access: 12.12.2018.

Josyula, V., Orr, M., Page, G. (2012): Cloud Computing. Automating the virtualized data centre. The United States of America: Cisco Press publishing house. ISBN: 978-1-58720-434-0.

Kagermann, H.,Helbig, J., Wahlster, W. (2013): Recommendations for implementing the strategic initative industrie 4.0. Frankfurt/Main. URL: < https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf> Last access: 19.10.2018.

Kaufmann, T., Forstner, L. (2014): Die horizontale Integration der Wertschöpfungskette in der Halbleiterindustrie - Chancen und Herausforderungen In: Bauernhansl, T.; Hompel, M. ten; Vogel-Heuser, B. (Eds.): Industry 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration. Wiesbaden: Springer Vieweg publishing house. ISBN: 978-3-658-04682-8.

Keuper, F., Brösel, G., Albrecht,T. (2009): Controlling in KMU: Identifikation spezifischer Handlungsbedarfe auf Basis aktueller Studien. Controlling fürkleine und mittlereUnternehmen. München: Oldenbourg publishing house.ISBN: 978-3-486-58634-3.

Kocovic, P. (2017): 3D printing and its impact on the production of fully functional components: Emerging research and opportunities. United states of America: IGI Global publishing house. ISBN: 9781522522898.

Kosmider, A. (1994): Controlling im Mittelstand: EineUntersuchung der Gestaltung und Anwendung des Controlling in mittelständischen Industrieunternehmen. 2. Edition. Stuttgart: Schäffer-Poeschel publishing house. ISBN: 978-3791005614.

Krämer,W. (2003): Mittelstandsökonomik: Grundzüge einerumfassenden Analyse kleiner und mittlerer Unternehmen. München: Vahlen publishing house. ISBN: 978-3800629992.

Krombholz, K., Frühwirt, P., Kieseberg, P., Kapsalis, I., Huber, M., Weippl, E. (2014): In: Tryfonas, T., Askoxylakis, I. (Eds.): Human aspects of Information security, privacy, and trust. Switzerland: Springer International publishing house. ISBN: 978-3-319-07620-1.

Kudyba, S. (2014): Big data, mining, and analytics: components of strategic decision making. New York: CRC Press publishing house. ISBN: 978-1-4665-6871-6.

Lee, E. A. (2008): Cyber Physical Systems: Design Challenges. URL:<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.156.1012&rep=rep1 &type=pdf> Last access: 20.11.2018.

Lee, I., Lee, K. (2015): The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons (2015) 58, 431-440.

Levy, M., Powell, P. (2005): Strategies for growth in SMEs, the role of information and information systems. 1. Edition. United Kingdom: Elsevier Butterworth-Heinemann publishing house. ISBN: 0750663510.

Loshin, D. (2013): Big data analytics: from strategic planning to enterprise integration with tools, techniques, NoSQL, and graph. United States of America: Morgan Kaufmann publishing house. ISBN: 978-0-12-417319-4.

Lu, S., Xu, C., Zhong, R.Y. (2016): An Active RFID Tag-Enabled Locating Approach With Multipath Effect Elimination in AGV, IEEE Trans. Autom. Sci. Eng. 13 (2016), 1333–1342.

Lucke, D., Constantinescu, C., Westkämper, E. (2008): Smart factory-A step towards the next generation of manufacturing. In: Mitsuishi, M., Ueda, K., Kimura, F. (Eds.): Manufacturing systems and technologies for the new frontier. London: Springer publishing house. ISBN: 9781848002661.

Lucke, D., Görzig, D., Kacir, M., Volkmann, J., Haist, C., Sachsenmaier, M., Rentschler, H. (2014): Strukturstudie "Industry 4.0 für Baden-Württemberg". Baden-Württemberg auf dem Weg zu Industry 4.0. Stuttgart.

Madhura, J. B., Kantilal P. R. (2014): Radio Frequency Identificatin (RFID) Misplaced Objects. International Journal of Electronic and Electrical Engineering, 7 (7), 657-662.

Mattern, F., Flörkemeier, C. (2010): Vom Internet der Computer zum Internet der Dinge. Informatik-Spektrum, 33, 107-121.

Mäder O. B., Hirsch B. (2009): Rationalitätssicherung als Controllingaufgabe in KMU. In: Müller, D. Controlling für kleine und mittlere Unternehmen. München: Oldenbourg publishing house. ISBN: 978-3-486-58634-3.

McGuire, P.M. (2009): Conveyors, application, selection, and integration. New York: CRC Press publishing house. ISBN: 978-1-4398-0390-5.

Medic, S., Pavlovoc, N. (2014): Mobile technologies in museum exhibitions. Turizam, 18(4), 166-174.

Milosevic, D.Z. (2003): Project management toolbox, tools and techniques for the practicing project manager. New Jersey: John Wiley & Sons publishing house. ISBN: 0-471-20822-1.

Mindas, M., Bednar, S. (2016): Mass customization in the context of Industry 4.0: Implications of veriety-induced complexity. In: Plinta, D., Matuszek, J. (Eds.):Advanced Industrial Engineering: Industry 4.0. ISBN: 978-83-927531-9-3.

Misic, V. B., Misic, J. (2015): Machine-to-Machine communications. Architectures, Technology, Standards and Applications. New York: CRC Press publishing house. ISBN: 978-1-466-6124-3.

Mitchell, P. E. (1998): Tool and manufacturing engineers handbook. 4. Edition. United States of America: Society of manufacturing Engineers publishing house. ISBN: 0-87263-489-2.

Moeller, D.P.F. (2016): Guide to computing fundamentals in cyber-physical systems. Concepts, design methods, and applications. Swizerland: Springer international publishing house. ISBN: 978-3-319-25178-3.

Morrish, J. (2015): Business models for machine-to-machine (M2M) communications. In: Anton-Haro, C., Dohler, M. (Eds.): Machine-to-machine (M2M) communications: Architecture, performance and applications. United Kingdom: Elsevier publishing house. ISBN: 978-1-78242-110-8.

Nakagawa, T. (2005): Maintenance theory of reliability. London: Springer publishing house. ISBN: 978-1-84628-221-8.

Neef, D. (2015): Digital exhaust: What everyone should know about big data, digitazation, and digitally driven innovation. United State of America: Pearson Education publishing house. ISBN: 978-0-13-383796-4.

Passerini, K., Tarabishy, A. E., Patten, K. (2012): Information technology for small business: managing the digital enterprise. New York: Springer science business media publishing house. ISBN: 978-1-4614-3040-7.

Price, K. (2013): QR codes for trainers. United State of America: American society for training & development publishing house. ISBN: 978-1-60728-525-0.

Pucihar, A., Lenart, G., Sudzina, F. (2010): ERP System selection criterion: SMEs' perceptions. In: Bharati, P., Lee, I., Chaudhury, A. (Eds.): Global perspectives on small and medium enterprises and strategic information systems: International approaches. New York: Business Science Reference publishing house. ISBN: 978-1-61520-628-5.

Pusala, M. K., Salehi, M. A., Katukuri, J. R., Xie, Y., Raghavan, V. (2016): Massive data analysis: Tasks, tools, applications, and challenges. In: Pyne, S., Rao, B. L. S. P., Rao, P., Rao, S. B. (Eds.): Big data analytics: methods and applications. India: Springer India publishing house. ISBN: 978-81-322-3628-3.

Reyes, P.M. (2011): RFID in the supply chain. The United States of America: McGraw-Hill publishing house. ISBN: 978-0-07-163498-4.

Roland Berger Strategy Consultants. 2014. Industry 4.0, The New Industrial Revolution: How Europe Will Succeed. International Conference The Next Industrial Revolution Manufacturing and Society in the XXI Century,Turin, November 14 – 15. URL: <https://www.researchgate.net/profile/Fauzi_Othman/publication/304614356_Industry_40_A_review_on_industrial_automation_and_robotic/links/57ac15aa08ae3765c3b7bab8.pdf> Last access: 20.01.2019.

Schröder, C. (2017): The Challenges of Industry 4.0 for Small and Medium-sized Enterprises. A good society –social democracy# 2017 plus. URL: <http://library.fes.de/pdf-files/wiso/12683.pdf> Last access: 04-09-2018.

Schöning, H. (2014): Data Mining und Analyse. In: Bauernhansl, T.; Hompel, M. ten; Vogel-Heuser, B. (Eds.) : Industry 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration. Wiesbaden: Springer Vieweg publishing house. ISBN: 978-3-658-04682-8.

Schöning, H., Dorchain, M. (2014): Data Mining und Analyse. Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien, Migration. Wiesbaden: Springer Vieweg publishing house.

Schwarz, C., Sauer, J. (2012): Towards decentralized AGV control with negotiations. In: Kersting, K., Toussaint, M. (Eds.): Stairs 2012, proceedings of the sixth starting AI researchers' symposium. Amsterdam: IOS Press BV publishing house. ISBN: 978-1-61499-096-3.

Shang, J. S. (1999): A material handling system selection model for a flexible manufacturing environment. In: Sarkis, J., Parsaei, H. R. (Eds.): Advanced manufacturing systems: Strategic management and implementation. Singapore: Gordon and Breach Science Publishing house. ISBN: 90-5699-673-8.

Simoes, D., Barbosa, B., Filipe, S. (2019): Smart marketing with the Internet of Things. United States of America: IGI Global publishing house. ISBN: 9781522557647.

Silva, C. W. D. (2016): Sensors and actuators: engineering system instrumentation. Second edition. The United States of America: CRC Press publishing house. ISBN: 978-1-4665-0682-4.

Singh, B. P. (2016): Refocusing with digital information services using quick response (QR) code in digital libraries and information centres: A trends to changing information landscape. In: Bhattackarya, P.K., Ganguly, S., Roy, P., Shukla, P., Deepa, N. (Eds.): Smart future: Knowledge trends that will change the world. India: TERI. ISBN: 978-81-7993-653-5.

Spath, D., Ganscher, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S. (2013): Produktionsarbeit der Zukunft – Industry 4.0. In: Das Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO. Stuttgart.

Srivatsan, T.S., Sudarshan, T.S. (2016): Additive manufacturing, Innovations, advances and applications. USA: CRC Press publishing house. ISBN: 978-1-4987-1478-5.

Thames, L., Schaefer, D. (2017): Industry 4.0: A overview of key benefits, technologies, and challenges. In: Thames, L., Schaefer, D. (Eds.): Cyber security for Industry 4.0: Analysis for design and manufacturing. Switzerland: Springer publishing house. ISBN: 978-3-319-50659-3.

Tseng Y., Yue, W.L., Taylor, M.A.P. (2005): The role of transportation in logistics chain. Australia.
URL:<https://pdfs.semanticscholar.org/45ef/db9ac3050f348bdb607a52e8062efb61813a.pdf> last access: 20.11.2018.

Ullrich, G. (2015): Automated guided vehicle systems: A primer with practical applications. 2. Edition. Berlin: Springer Heidelberg publishing house. ISBN: 978-3-662-44814-4.

User guide to the SME definition. Luxembourg: Publications Office of the European Union, 2015. ISBN 978-92-79-45301-4. URL:<http://ec.europa.eu/regional_policy/sources/conferences/state-aid/sme/smedefinitionguide_en.pdf>Last access: 29-08-2018.

Ustundag, A., Cevikcan, E. (2018): Industry 4.0: Managing the digital transformation, 1.Edition. Switzerland: Springer publishing house. ISBN: 978-3-319-57869-9.

Verl, A., Lechler, A. (2014): Steuerung aus der Cloud In: Bauernhansl, T.; Hompel, M. ten; Vogel-Heuser, B. (Eds.): Industry 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien und Migration. Wiesbaden: Springer Vieweg publishing house. ISBN: 978-3-658-04682-8.

Verzuh, E. (2003): The portable MBA in project management, a complete reader to project management from the leaders in the field, the latest principle and strategies as well as new application of tried-and-true methods. New Jersey: John willey & son Inc publishing house. ISBN: 0-471-26899-2.

Weber, M. (2013): Management von Big-Data-Projekten. Leitfaden. In: Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. (BITKOM). Berlin.

Westkämper, E. (2013): Struktureller Wandel durch Megatrends In: Westkämper, E.; Spath, Dieter; Constantinescu, C.; Lentes, J. (Eds.): Digitale Produktion. Berlin: Springer publishing house. ISBN: 978-3-642-20259-9

Wilson, M. (2015): Implementation of robot systems: An introduction to robotics, automation, and successful systems integration in manufacturing. United States of America: Elsevier publishing house. ISBN: 978-0-124-04733-4.

Winter, M. (2010): Scan me: Everybody's guide to the magical world of QR codes, barcodes, mobile devices and hyperlinking the real to the virtual. California: Westsong publishing house. ISBN: 978-0-9659000-3-4.

Yang, L., Hsu, K., Baughman, B., Godfrey, D., Media, F., Menon, M., Wiener, S. (2017): Additive manufacturing of metals: The technology, materials, design and production. Switzerland, Springer publishing house. ISBN: 978-3-319-55128-9.

Zhang, Z. N., Li, X., Wang, X., Cheng, H. (2017): Decentralized cyber-physical systems: A paradigm for cloud-based smart factory of Industry 4.0. In: Thames, L., Schaefer, D. (Eds.): Cyber security for Industry 4.0: Analysis for design and manufacturing. Switzerland: Springer publishing house. ISBN: 978-3-319-50659-3.

Zhao, F., Guibas, L. (2009): Communications engineering desk references. United States of America: Elsevier publishing house. ISBN: 978-0-12-374648-1.

URL:<https://www.hopelandrfid.com/industry-4-0-smart-manufacturing_n40> Last access: 02.01.2019.