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„Industry 4.0 in a Global Context – a comparative analysis of Germany, U.S.A and China“

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Abstract

In 2011 Germany introduced the term Industry 4.0 – the fourth industrial revolution. Connected to the term is a concept shaping Germany's industry towards this new era. A new era where physical and virtual world combine and components like the Internet of Things and Services, Cyber-Physical Systems and Smart Manufacturing play an important role. The topic gained a lot of attention all over the world. Several countries followed suit and came up with similar initiatives addressing the topic. China introduced Made in China 2025 and Internet Plus. The U.S.A the Industrial Internet Consortium and Advanced Manufacturing Partnership. All three countries are addressing the same topic but differentiate in the way of implementation and understanding. The aim is to analyze the initiatives and to find out to which degree differences and similarities in the way of understanding and implementation are visible when comparing Germany, U.S.A and China. The overall goal is similar: becoming the leading country in this new market. Germany and the U.S. are well prepared considering their level of industrialization whereas China has to master Industry 2.0, 3.0 and 4.0 at the same time. The initiatives differentiate in their way of execution (government or market driven) and focus areas. The U.S.A. focuses on software rather on hardware, Germany on both and China aims at a total restructuring of manufacturing industry by setting quantifiable goals.

Keywords: Industry 4.0, Industrial Internet Consortium, Advanced Manufacturing Partnership, Made in China 2025, Internet Plus, Germany, China, U.S.A,

JEL Classification: O14, M15

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III List of Abbreviations

Acatech	National Academy of Science and Engineering
AI	Artificial Intelligence
AMP	Advanced Manufacturing Partnership
BITKOM	German Federal Association for Information Technology, Telecommunications and New Media
CEO	Chief Executive Officer
CNY	Chinese yuan
CPS	Cyber-Physical Systems
EUR	Euro
GDP	Gross Domestic Product
IBM	International Business Machines Corporation
ICT	Information and Communications Technology
ID	Identification
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
IoS	Internet of Services
IoT	Internet of Things
IT	Information Technology
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
OMG	Object Management Group
RAMI40	Reference-Architecture-Model Industry 4.0
SMEs	Small and Medium Sized Enterprises
U.S.	United States
U.S.A.	United States of America
USD	United States Dollar
VDMA	Mechanical Engineering Industry Association
ZVEI	Central Association of the Electrical Engineering and Electronics Industry

1 Introduction

1.1 Research Problem

The world has become more dynamic than ever before. Changes are happening rapidly especially in terms of technology and its use. New terms are introduced on a frequent basis and one has to be careful to be able to catch up. Moreover, the risk is given that not everyone has the same understanding of those terms as they are often used inflationary. Therefore, it is of great importance to understand the differences which exists on an international level.

Trends of the digital world such as Augmented Reality, Internet of Things, Smart Products and Machine Learning are present in people's heads and maybe already part of daily life. Sometimes, one does not even realize how often confrontation exists as the definitions are not clear. Consequently, it is necessary to develop a common understanding for the trends of today.

In the past decade another term has gained a lot of attention: Industry 4.0. The term was shaped in Germany. It has been introduced as a vision for the future of industry in the context of a fourth industrial revolution. The term spread across Europe and the rest of the world very fast. Unfortunately, the joint usage of the term Industry 4.0 does not guarantee a compatibility of definitions and concepts. Countries set different focuses as they might be on different levels of industrialization, digitalization and automation. Hence, to fully understand the interpretation and implementation of Industry 4.0 in each country one has to analyze the different initiatives and how they evolved.

Three industrialized nations which have dealt intensively with the topic of Industry 4.0 are Germany the pioneer of the term, U.S.A and China. Those nations are world leading economies thus, it is interesting and at the same time essential to take a closer look at the three nations. They are shaping the world's economy by introducing concepts and standards and are competing in a constant race for first place. The manufacturing industry is a key component in this race and therefore, Industry 4.0 plays a crucial role. Different approaches exist to meet the requirements of Industry 4.0 and to generate economic advantages. The three countries have established different strategies to adapt to the new era of industry. Germany as the first mover introduced “Industry 4.0”, the U.S. established the “Industrial Internet Consortium” and the “Advanced Manufacturing Partnership” and China “Made in China 2025” and “Internet Plus”. A variety of objectives and technical components exist within those strategies. Moreover, the three countries have different focus areas in accordance to the stage of industrialization they are currently in and the challenges they are facing. To create an overall picture of the new era of industry the different strategies have to be analyzed in detail.

The thesis aims at comparing and analyzing the conception and implementation of Industry 4.0 and its resulting strategies in Germany, U.S.A and China. Every country in its own way is addressing the opportunities and challenges that Industry 4.0 entails. The focus lies on the question to which degree differences and similarities in the way of understanding and implementation are visible when comparing Germany, U.S.A and China.

1.2 Research Method

The thesis addresses the topic of Industry 4.0 in a global context by comparing the initiatives in Germany, U.S.A and China. By using a literature-based approach the state of the art of the topic can be presented and the research question answered.

1.3 Course of Investigation

This work is divided into seven chapters. Chapter one introduces the research problem of the thesis as well as the structure of the work. It provides an overview of the topic being discussed in the following chapters and explains the focus of the thesis.

Chapter two concentrates on the theoretical background around Industry 4.0. It starts with the evolution of Industry 4.0 and the origin of the term will be explained. Followed by a definition of the fourth industrial revolution and how it evolved. Moreover, it will be pointed out how the term and its suffix are being used in order to establish clarity of the trend that currently exists. Furthermore, an overall definition of the term and its components will be in focus in chapter two. Cyber-Physical Systems, Internet of Things, Internet of Services and Smart Factory will be explained in detail.

The third chapter examines Germany and its strategy towards Industry 4.0. The history of Germany's manufacturing industry and the development it has gone through will be closely looked at, and the starting position of Germany becomes clear. Building on this, the concept and the components of Industry 4.0 as well as the key areas are introduced. Following eight key areas are being explained in detail: Standardization and Reference Architecture, Managing Complex Systems, Comprehensive Broadband Infrastructure for Industry, Safety and Security, Work Organization and Design, Training and Continuing Professional Development, Regulatory Framework and Resource Efficiency. Also, the role of Platform Industry 4.0 and the vision and center of Germany's Industry 4.0 will be examined. The chapter concludes with a brief look into international cooperation in terms of Industry 4.0.

In chapter four, the U.S.A are in focus. By looking in detail into their manufacturing industry and current situation an introduction to the topic is being created. Furthermore, the understanding of Industry 4.0 in the U.S.A is elaborated upon and differences are highlighted. The Industrial Internet Consortium and its goals can be found in subchapter 4.3. The chapter finishes off with a detailed evaluation of the governmental Advanced Manufacturing program. Focus of this subchapter are technical priorities such as Smart and Digital Manufacturing, Advanced Industrial Robotics, Infrastructure for Artificial Intelligence and Cybersecurity in Manufacturing.

Chapter five introduces the last country of the comparative analysis - China. Here, again the beginning marks the overview of manufacturing industry. Additionally, technical infrastructure of China plays a role in this chapter. Continuing with the fourth industrial revolution and its strategy Made in China 2025. The strategy focuses on five initiatives (R&D and Innovation Centers, Smart Manufacturing Projects, Industrial Bases, Green Manufacturing Projects and High-end Equipment Manufacturing Projects) which will be further explained. The focus in subchapter 5.3.3 is dedicated to smart manufacturing in China and taking into account why and how China is implementing it. Furthermore, the existing international cooperation between Germany and China is mentioned. The chapter closes with analyzing the second strategy China has launched to achieve its goal: Internet Plus Strategy.

The sixth chapter compares the three countries and their initiatives in detail to be able to draw a conclusion about existing similarities and differences. Subchapter 6.1 aims at creating clarity of the chronological classification of the initiatives. Moreover, the implementation of concepts is analyzed further by looking at the overall strategic goals, starting position, initiatives execution and focus of the programs. Chapter six concludes by providing a short overview of the status quo in implementation of initiatives.

In chapter seven the research question will be answered by summarizing the findings of the previous chapters. Furthermore, a critical acclaim and an outlook to the topic will be presented.

2 Theoretical Background

2.1 The evolution of Industry 4.0

2.1.1 The German Initiative

The concept Industry 4.0 is a high-tech strategy proposed by the German Government (Sun et al., 2018, p. 51). It was first introduced in 2011 at the Hanover fair – the world's leading fair of industry (Sukhodolov, 2019, p. 5). It marks a realignment of industry, which redefines working structures in companies from planning to implementation to sales (Köhler et al., 2015, p. 17). Germany's future competitiveness in the manufacturing industry shall be secured through the initiative (Müller and Voigt, 2018, p. 660). It was designed as a future oriented project by the National Academy of Science and Engineering (in the following acatech) together with the Mechanical Engineering Industry Association (in the following VDMA), the Central Association of the Electrical Engineering and Electronics Industry (in the following ZVEI), the German Federal Association for Information Technology, Telecommunications and New Media (in the following BITKOM), research institutes, universities and other well-known companies (Kaufmann, 2015, p. 4). The German Government even made the initiative part of their "High-Tech Strategy 2020 for Germany" (Ślusarczyk, 2018, p. 233). The "High-Tech Strategy 2020" focusses on five pillars: future prosperity and quality of life, consolidation of resources and promoting transfer, strengthening the dynamism of innovation in industry, creation of favorable conditions for innovation and strengthening of dialogue and participation (Federal Ministry of Education and Research, n.d.).

Industry 4.0 has its origin in Germany and was at least for some time only known in German-speaking countries.

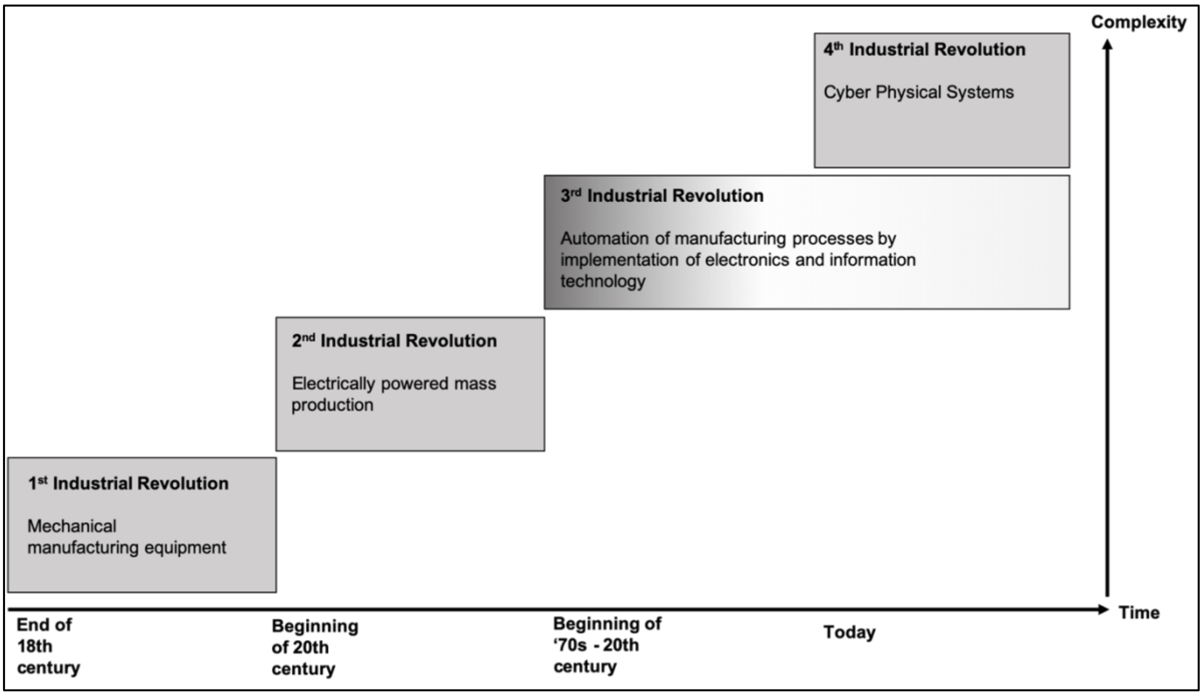
But since the introduction the concept has gained more and more attention. The term started to be used without reference to the German initiative as a synonym for a new era of industry (Müller and Voigt, 2018, p. 660). Furthermore, other countries around the world have implemented similar initiatives or their *own* Industry 4.0 concept supported by their government or private companies. To name a few: France – "Nouvelle France Industrielle"; Italy – "Fabricca Intelligente"; U.S.A – "Industrial Internet Consortium" and China – "Made in China 2025" (Ślusarczyk, 2018, p. 233; Kagermann et al., 2016, pp. 9 – 12). This demonstrates that after the introduction of the term the world has started to put an even greater emphasis on the further development of industry and production technology (Köhler et al., 2015, p. 17).

2.1.2. The Fourth Industrial Revolution

Industry 4.0 is often referred to as the fourth industrial revolution. The term revolution is defined as a sudden and radical change (Schwab, 2016, p. 6). The suddenness may take years to fully unfold, as seen 10,000 years ago when the agrarian revolution took place and a shift from foraging to farming occurred (ibid.). That is why it has often been discussed, whether the term "revolution" is even suitable for an ongoing process (Bartodziej, 2017, p. 33).

In order to understand the term Industry 4.0 and the reference to the fourth revolution one has to have a closer look at the pasts development. Figure 1 illustrates the four different industrial revolutions.

Figure 1: The Four Industrial Revolutions



Source: Own Source Based on Kagermann et al., 2013, p. 17

The agrarian revolution was followed by the first industrial revolution which took place from about 1760 to 1840 (Schwab, 2016, p. 6). It was driven by the introduction of mechanical manufacturing equipment (Bartodziej, 2017, p. 32) and based on the further development of the already existing coal fired steam engine by James Watt in 1769 (Hug, 2018, p. 10). With his development he was able to use three quarters of coal less and also financially it was a great success (ibid.). Watt had the machine patented and was able to take a fee for the amount of coal saved from the people who used his technology (ibid.). Countries like England, Germany and the U.S.A., with high coal reserves, adapted Watts technology very quickly (ibid., p. 11). The second industrial revolution started in the beginning of the 20th century and was shaped by Ford's assembly line production in the United States (Drath, 2017, p. 18). The productivity increased massively, and Ford was able to double the workers' wage as well as decrease the sales price of the cars from USD 870 to USD 370 (ibid.). The second industrial revolution was a historical transformation regarding economy, production and labor development (Sendler, 2013, p. 6). The 1970s were impacted by electronics and information technology. This is when the third industrial revolution began (Schwab, 2016, p. 7). During the third industrial revolution the automation of manufacturing processes increased, and machines were able to take over and replace a large share of labor work (Bartodziej, 2017, p. 32). The third industrial revolution introduced digital and programmable logic controller, mainframe computer and personal computer that moved into offices as well as private households (Drath, 2017, p. 18). This had socio-economic and socio-cultural effects. A new industrial sector had been established, but at the same time workforce was replaced by machines (Bartodziej, 2017, pp. 32 – 33). The third revolution is a process that is still ongoing, as seen in figure 1 and is already overlapping with a new age of industrialization: the fourth industrial revolution (ibid.). Remarkable at this point is the fact, the fourth industrial revolution has not taken place yet but is still being referred to as it has happened already (Drath, 2017, p. 19). Nevertheless, one cannot forget the previous industrial revolutions took decades to develop (Sendler, 2013, p. 7). It is the continuation of the digital revolution that started within the third industrial revolution and involves the further development of already existing technological innovations (Hug, 2018, p. 14). Virtual and physical systems of manufacturing shall globally cooperate in a flexible way (Schwab, 2016, p. 7). The technologies stimulating the fourth industrial revolution derived from the learnings generated in the prior industrial revolutions (Schwab, 2018, p. 7). Such technologies are for example artificial intelligence (in the following AI) and robotics, additive manufacturing, neurotechnology, biotechnology, virtual and augmented reality, new materials, energy technologies, Cyber-Physical Systems as well as technologies which we do not know exist (ibid.)

2.1.3 Versioning

Academic literature, the news, the digital world rarely mentions the phrase the fourth industrial revolution, but rather Industry 4.0. The term Industry 4.0 clearly polarizes (Drath, 2017, p. 18). When following publications and discussion related to industrial or economical change one cannot avoid the label digitalization nor 4.0 (Paul, 2016, p. 2). The term is most of all effective as a marketing tool spreading quickly around the world (Sendler, 2016a, p. 6). Industries try to get across to their customers their products mirror exactly what Industry 4.0 is all about (ibid.). A “4.0-Hype” has been established – but why? The versioning started with the term “Web 2.0” and “Web 3.0”, terms that did not imply new technologies but new socio-technical usage of internet (Paul, 2016, p. 2). The suffix “4.0” reminds of the release of a new software version and makes the manufacturing industry sound modern, clean and innovative which fits in the time of internet, mobility and cloud computing (Sendler, 2016a, p. 6). But still to a wider public the meaning of Industry 4.0 is not clear and controversy discussions have been initiated (Drath, 2017, p. 18). The suffix is used in an inflationary way such as “Consulting 4.0”, “Energy 4.0”, “Gender 4.0”, “Labor 4.0” etc. – without guarantee of compatibility of concepts (Paul, 2016, p. 2). The eager usage of the term or the suffix are disguising the center of what Industry 4.0’s vision stands for (Drath, 2017, p. 18). One may argue that this is going to trigger even more negative discussions but the increasing public and also the political interest due to the “4.0-Hype” can have a positive influence (Sendler, 2016a, p. 6). The more people are discussing about the significance and its purpose of Industry 4.0, the faster a change might be seen (ibid.).

2.2 Defining Industry 4.0

In the previous section it has been made clear the term Industry 4.0 was established in Germany and there is a concept connected to the term as part of a governmental strategy. Nevertheless, the term is not only applicable to the German concept, but to a broad development in industry all over the world. The conceptual idea of Industry 4.0 has been widely adopted by other industrial nations (Gilchrist, 2016, p. 195). In conclusion there are several definitions of Industry 4.0 as the topic has become a top priority for many researcher and companies. The founders of the term (acatech, VDMA, ZVEI and BITKOM) have defined it as following: Industry 4.0 is a new era of organization and control of value chain (Herausgeberkreis BITKOM e.V., VDMA e.V., ZVEI e.V., 2015, p. 8). The life cycle of products is going to be steadily adapted to induvial customer’s needs, based on availability of relevant information in real-time which derive from linkages of all instances involved in the value chain (ibid.). Connection of people, objects and systems establishes dynamic real-time optimization and self-organized, cross-organizational value-adding networks (ibid.).

This definition seems to be more a vision than a precise definition. In 2013 Kagermann et al. (p. 8) already defined the term more precise by saying the core of Industry 4.0 is technical integration of Cyber-Physical Systems in production and logistics as well as usage of Internet of Things and Services. Nevertheless, a generally accepted clear definition does not exist yet (Bauer et al. 2014, p. 18). By reviewing academic literature there are characteristics and components frequently named in the context of Industry 4.0 which are completing the picture of what Industry 4.0 is all about.

Substantial value-added processes such as development, logistics and production are affected by Industry 4.0 (Kaufmann, 2015, p. 4). A special characteristic of Industry 4.0 is the use of machine data in context of production processes (ibid., p. 5). Data which is being produced in downstream processes can be used to actively control and influence the present process (ibid.). Moreover, several economic and technical trends are playing an essential role for Industry 4.0 and are important to integrate when trying to define Industry 4.0. Integral trends are digitalization, change of value-added networks, individualization of customer requirements, changes in business models and embedded systems (Kaufmann, 2015, p. 2). Digitalization has been part of Industry 3.0 already and is a still ongoing process. Most of produced products do not only consist of hardware anymore but have a high percentage of software parts (Kaufmann, 2015, p. 3). The number of products connected to internet is steadily increasing and it is expected to reach the number of 50 billion products with internet connection by 2020 (ibid.). Moreover, customer requirements are getting more sophisticated and specific therefore, production is facing the challenge to adjust features of products to the needs (ibid.). In addition, long-established businesses need to overthink their business models in order to keep up with companies already working more towards customers individualization (ibid.). Embedded systems are characterized by interaction between mechanics, software and hardware and only interaction between sensors, actuators and software make it possible to have the complex functionalities available today (Bens et al., 2010, pp. 1 – 4). Embedded systems are going to play a more and more important role as a greater number of products and machines will be equipped with complex functions. Furthermore, there are several technical components included in the definition of Industry 4.0 which are not new at a first glance. The interaction between those features are making those components special in the context of Industry 4.0. Those features or components are Cyber-Physical Systems, Internet of Things, Internet of Services and Smart Factory (Bartodziej, 2017, pp. 34 – 35; Hermann et al., 2015, p. 8). They are forming the technical basis of Industry 4.0 and will be further elaborated upon in the following subchapters.

To round off the overall definition of Industry 4.0 it is once again important to acknowledge the complexity of the term. It is a very current topic and therefore a considerable amount of definitions are existing, making the term sometimes even more blurry than concrete. To conclude, Industry 4.0 is where digital and physical world are seamlessly interconnected and products play an active role in the production process (Russwurm, 2013, p. 31).

2.3 Technical Components

2.3.1 Cyber-Physical Systems

The term Cyber-Physical Systems (in the following CPS) was first mentioned 2006 in the United States when National Science Foundation (in the following NSF) announced it to be one of the core elements of national research (Sendler, 2013, p. 8). It evolved from a combination of trends of the last decades in computer science and information technology (Lüth, 2017, p. 25). CPS are a combination of software with mechanical and electronical parts which communicate and interact via a data infrastructure and do have a physical in- and output (Kaufmann, 2015, p. 13; Sendler, 2013, p. 8). Moreover, a reliable wireless network infrastructure is needed in order to assure a steady communication (Möller, 2016, p. 107). In addition, there are more characteristics identifying CPS. Not all of the following attributes need to necessarily be included in CPS, but they can be seen as a reference (Lüth, 2017, p. 26). As already mentioned, CPS are a combination of virtual and physical world. Furthermore, they adapt to environment, act autonomous and cooperative, are able to communicate and cooperate with human beings and are a system of systems (Lüth, 2017, p. 26). The best-known example of a Cyber-Physical System is the smartphone. CPS do exist in all sizes. They can be as small as a smartphone or an autonomous robot, but also as big and complex as a railway system (Lüth, 2017, p. 26). CPS are predicted to play an even more important role in the future as they are already doing. Especially in terms of industry as they go beyond the traditional systems being used by the majority (Möller, 2016, p. 107). In the context of Industry 4.0, CPS can be found in production systems characterized by interconnected and flexible production (Lüth, 2017, p. 28).

2.3.2 Internet of Things

The term Internet of Things (in the following IoT) goes back to 1999 when British technology pioneer Kevin Ahston described a system which connects physical objects to internet via sensors (Rose et al., 2015, p. 7). The definition provided by Kagermann et al. (2013, p. 85) describes IoT as a linkage between physical objects and a virtual internet(-like) structure. Via sensor and actuator technology, states can be captured, and actions can be taken (ibid.). The opportunities of IoT products are endless. More and more products are being connected to internet, from printer to coffee machines. Those smart products are collecting data via sensors that are being analyzed and used to increase intelligence of products in order to lead to more autonomy (Magagnoli, 2018, p. 16). IoT devices are transforming the way people live as internet-enabled appliances, home automation components, energy-efficiency, fitness and health monitoring devices are influencing our behavior (Rose et al., 2015, p. 4). Cost savings and security are only a few side effects. It is predicted, especially for the elderly population IoT devices are going to be a great help and support for independence (ibid.). IoT are not only of high interest for private users. In production industry and therefore for Industry 4.0, IoT are an important topic as well (Rose et al., 2015, p. 4)

2.3.3 Internet of Services

Whereas the Internet of Things links physical objects (devices) with a virtual internet(-like) structure, services through internet are provided by the Internet of Services (in the following IoS) (Burritt and Christ, 2016, p. 28). IoS are offering services and functionalities by providers as web-based software components based on actual demand (Kagermann et al., 2013, p. 85). Companies are able to create flexible combinations and solutions through individual software components (ibid.). This is leading to a customer-oriented offering approach where manufacturers have to think about how their product can become a service with a long-term advantage for their customer (Bartodziej, 2017, p. 55).

2.3.4 Smart Factory

Industry 4.0 is characterized by efficiency and intelligence of physical objects and therefore the Smart Factory, which is dominated by complexity and efficiency, is a core element (Kagermann, et al., 2013, p. 23). A Smart Factory uses information and communication technology for production, logistics and coordination in order to create a futuristic factory able to respond flexible to inquiries (ibid., p. 87). Like in a social network, people, machines and resources are communicating with each other to sustain and increase effectivity (ibid.). In a Smart Factory, an intelligent infrastructure with interfaces between e.g. smart mobility, smart logistics and smart grids is in place (ibid., p. 23). Smart Factories have been with us for a longer time already and did not only appear with the beginning of Industry 4.0. They are not only intelligent machines or robots. A Smart factory may also appear in a lighter version where technology is used to reduce for example waste by reducing the number of production lines and at the same time not reducing the output (Gilchrist, 2016, p. 218). In conclusion, a Smart

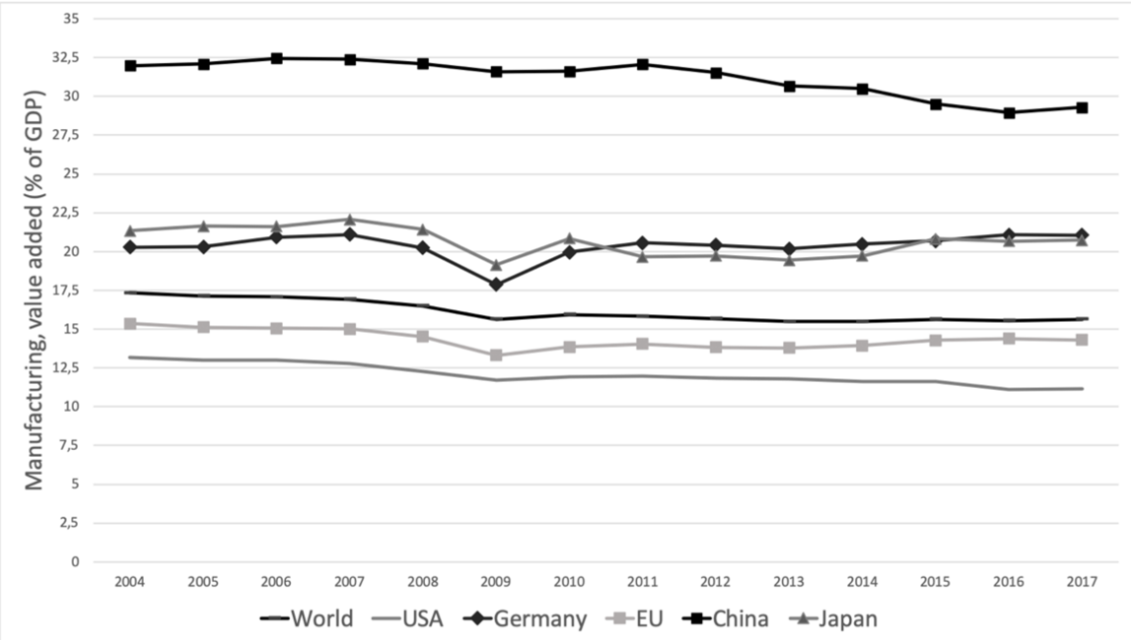
Factory makes production appealing from an economic perspective as the digital and physical world connects (Kagermann et. al., 2013, pp. 24 – 25).

3 Germany

3.1 Manufacturing Industry

Germany as a global leader in the area of manufacturing has one of the most competitive industry locations in the world (Rojko, 2017, p. 80). The country has the ability to control complex industrial processes by already applying information and communication technology for decades (Kagermann et al., 2013, p. 17). Technology and knowhow are being used in 90 percent of all industrial production processes (ibid.). Not only IT technology but also specialization in research and development contributes to Germany's success (Bartodziej, 2017, p. 31 ff.). After China, the United States and Japan, Germany is the fourth biggest industrialized nation (ibid.). 22 of Germany's 100 best small and medium-sized enterprises (in the following SMEs) are machinery manufacturers and one sixth of Germany's workforce is employed in the manufacturing industry (Kagermann et al., 2013, p. 18). The manufacturing industry can be seen as the backbone of Germany's economy (Kagermann, 2015, p. 23). Also, on international level Germany can keep up against competitors. Over the past 13 years Germany was able to maintain quite a stable share of manufacturing value added (GDP) as seen in figure 2.

Figure 2: Manufacturing Value Added (% of GDP)



Source: Own source based on Worldbank 2019

Even after the financial crisis in 2007, Germany's manufacturing industry was able to recover rapidly until 2011 and the countries competitiveness played an essential role in this process (Worldbank, 2019). Many industry representatives argue the main competitors in the machinery and plant manufacturing industry are domestic German companies (Kagermann et al., 2013, p. 18). The manufacturing industry is also able to accomplish a trade surplus year after year (Kagermann, 2015, p. 23). The predictions for Germany's position as a leading future manufacturing industry are positive as well (Kagermann et al., 2013, p. 19). It is important for Germany to stay competitive now and keep up with the wave of innovations that is occurring already (Kagermann, 2015, p. 24).

3.2 The Concept Industry 4.0

3.2.1 Introduction

One main goal of Germany, which has already been identified, is to secure the future competitiveness in manufacturing industry. In order to do so the future-project Industry 4.0 had been created. The project was launched 2011 by acatech, VDMA, ZVEI and BITKOM together with participants from various research institutions (Kaufmann, 2015, p. 4). The founding fathers of the concept Industry 4.0 are Henning Kagermann (president of acatech), Wolf-Dieter Lukas (ministerial director at the Federal Ministry of Education and Research) and Wolfgang Wahlster (former CEO of German Research Centre for Artificial Intelligence) (Syska and Lièvre, 2016, p. 77).
The aim of the initiative is to prepare Germany for an internet-driven fourth industrial revolution. Germany is already in a leading position in automotive, mobile and mechanical engineering as well as in software-intensive embedded systems (Kagermann et al., 2011, p. 2). To become a leading provider in this new market by 2020 the next steps need to be taken towards Internet of Things in the industrial environment (ibid.). Hence, on January 25th of 2011 the Communication Promoters Group of the Industry-Science Research Alliance proposed its recommendations for action to the Federal Government (ibid.). German Government adopted the initiative as part of their High-Tech Strategy 2020 Action Plan in November 2011 (Kagermann et al., 2013, p. 77). After the approval by German Government, the Industry 4.0 Working Group started to work on recommendations for implementing the initiative (Kagermann et al., 2011, p. 2). The recommendations were presented to Government

at the Industry-Science-Research Alliance Implementation Forum on 2nd of October 2012 (Kagermann et al., 2013, p. 77).

3.2.2 Components of the Concept

3.2.2.1 Key Areas

Germany's goal is to shift industrial production towards Industry 4.0 and can become a leading supplier of smart manufacturing technologies through integrating information and communication technology (Kagermann et al., 2013, p. 6). Furthermore, a dual strategy is aimed at where also a new leading market for CPS technologies and products need to be created (ibid.). In order to do so, following features need to be utilized: horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain and vertical integration and networked manufacturing system (ibid.). Additionally, the Working Group has identified the following eight key areas where action needs to be taken: standardization and reference architecture, managing complex systems, a comprehensive broadband infrastructure for industry, safety and security, work organization and design, training and continuing professional development, regulatory framework and resource efficiency (ibid.). Action areas will be characterized in detail in the following subchapters.

3.2.2.2 Standardization and Reference Architecture

To secure a well working integration throughout value networks, standardization is required. Companies need to be able to combine their diverse approaches into one common approach. Cooperation between machinery and plant manufacturing, automation engineering and software companies require common terminology and existing standards need to be incorporated into a global reference architecture (Kagermann et al., 2013, p. 43). A reference architecture shall combine the previous tasks and processes of manufacturing with Industry 4.0 aspects (Sendler, 2016b, p. 60). It has to be a system as generic as possible in order to be applied to any product and industry (ibid.). The reference architecture is a framework providing structuring, development, integration and operation of the technological systems (Kagermann et al., 2013 p. 43). In April 2015 a reference architecture by the title "Reference-Architecture-Model Industry 4.0" (in the following RAMI40) was introduced (Sendler, 2016b, p. 61). RAMI40 is combining the challenges named earlier on and provides the standard for further development.

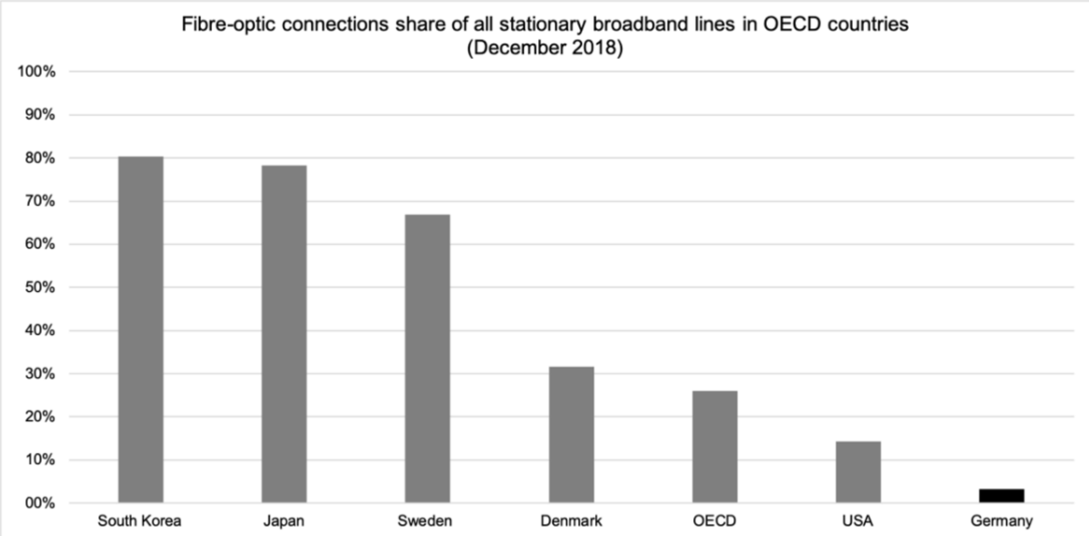
3.2.2.3 Managing Complex Systems

Individualization of products, increasing functionality and increasing integration of different technologies lead to a complexity of systems (Kagermann et al., 2013, p. 46). Modeling has been identified as one central aspect to manage the growth of complexity in times of Industry 4.0 (ibid.). Hence, awareness needs to be raised among the engineering community as well as provision of methods and tools for using models to visualize real-world systems in the virtual world (ibid, p. 47). In conclusion, a Working Group has been established to focus on the topic of modelling related to managing complex systems in manufacturing engineering (ibid., p. 48). Within the group best practices are being shared and guidelines and recommended actions are being developed (ibid.).

3.2.2.4 Comprehensive Broadband Infrastructure for Industry

When comparing the number of broadband connections of the leading countries world-wide, Germany is in a good position (ITU, 2019). China led the list in 2018 with 407.38 million connections, followed by U.S.A and Japan with 116.47 million and 40.91 million (ibid.). Germany was listed in fourth place with 34.15 million broadband connections (ibid.). In times where higher-volume and high-quality data is being exchanged a reliable communication network is needed (Kagermann et al, 2013, p. 49). Therefore, the necessary infrastructure needs to be developed. Germany may be a leading power in broadband connections, but not in the quality of connections in terms of fibre-optic connections. With a share of 3.2%, Germany ranks low compared to other OECD countries as figure 3 illustrates.

Figure 3: Fibre-optic connections in OECD countries



Source: Own Source based on OECD 2019

Hence, it is not surprising Germany sets the objective to further develop the existing communication networks. Expanding internet infrastructure needs to be done on a massive scale in order to secure accessibility to a large number of users (Kagermann et al., 2013, p. 50).

3.2.2.5 Safety and Security

Safety and Security are part of the initiative since issues regarding the topic have often only been raised once the problem occurred (Kagermann et al., 2013, p. 50). Since Industry 4.0 involves cooperation and networking between several stakeholders, differences in the level of security awareness in different industries need to disappear to avoid the spread of viruses or cyber-attacks (ibid.). Eight priority areas for action have been characterized by the Working Group to fight the threats: integrated safety and security strategies, architectures and standards, unique and secure IDs for products, processes and machines, a migration strategy from Industry 3.0 to Industry 4.0, user-friendly safety and security solutions, safety and security in a business management context, secure protection against product piracy, training and (in-house) continuing professional development and “community building” for data protection in Industry 4.0 (ibid., pp. 50 – 51). While focusing on the priority areas it is important to consider how to find a pragmatic solution. The pragmatic solution may be a *roadmap* for safety and security issues or a list of requirements (Kagermann et al., 2013, pp. 51 - 54).

3.2.2.6 Work Organization and Design

Technological change also requires a change the way human beings are working. Employees are being challenged especially in terms of complexity and problem-solving (Kagermann et al., 2013, p. 57). Recommendations have been made to set up a regular dialogue to identify key problems and potential solutions to face the issue of people and work in Industry 4.0 (ibid., p. 58). Main objectives within this area are to document the actions required to achieve employee-oriented labor and training policies, provide guidelines to establish a socio-technical approach (cooperative and self-organized interactions between employees and technology operating systems) and create lifelong learning for the workforce (ibid.).

3.2.2.7 Training and Continuing Professional Development

As it has been described above, jobs and skills will change due to new organizational and operational structures and the interaction of real and virtual machines. Measures with regard to qualifications, training and continuing professional development need to be taken. This includes the development of strategies, establishment of “best practice networks” focusing on supporting knowledge transfer and skill acquisition by new teaching methods (Kagermann et al., 2013, p. 59). Furthermore, the focus of Industry 4.0-specific learning content is to acquire a mutual understanding between all industries (ibid.). The Working Group has created a concept called “Academy Cube” which offers up to twelve courses in the area of Industry 4.0 (ibid., p. 60). It has been launched by German and international industrial enterprises as a solution for the required new training formats and content derived from Industry 4.0 (ibid.).

3.2.2.8 Regulatory Framework

There are several challenges confronting Germany within Industry 4.0 which could be solved by providing a regulatory framework. Four essential challenges identified as most essential are named by Kagermann et al. (2013, pp. 62 - 64): protecting corporate data, responsibility and liability of a wider range of matters, handling personal data and the possibility of trade restrictions. Actions will be taken by involving legal experts in the process of establishing a regulatory framework and moreover providing engineers with a basic understanding of legal issues (ibid., p. 65).

3.2.2.9 Resource Efficiency

Within the manufacturing industry a substantial amount of raw materials is being used. A key issue within Industry 4.0 is to provide evidence that the additional use of resources in establishing CPS, generates resource productivity and efficiency gains during engineering and manufacturing (Kagermann et al., 2013, p. 66). This goes hand-in-hand with keeping an eye on eco-friendliness of production processes (ibid., p. 67). Key performance indicators need to be developed and established to assess the resource efficiency. However, it requires further research and development (ibid.).

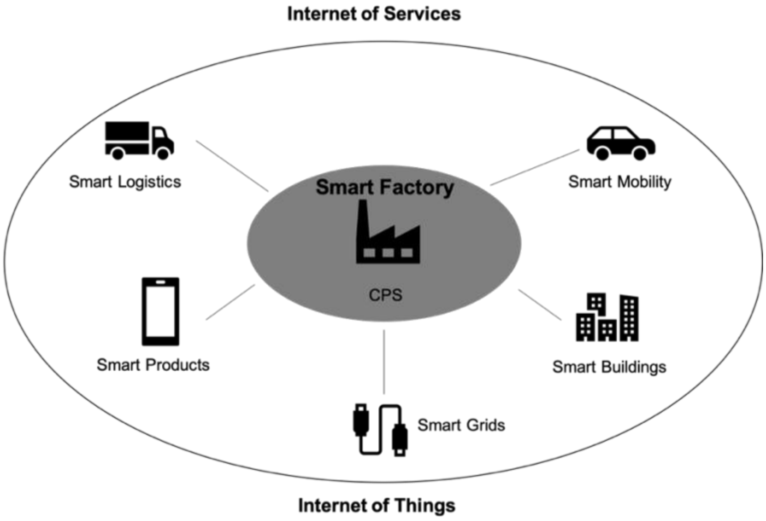
3.2.3 Platform Industry 4.0

After successfully launching the report on recommendations for future project Industry 4.0, the associations of ZVEI, BITKOM and VDMA announced a cooperation agreement – Platform Industry 4.0 (Plattform Industrie 4.0, 2019b). The platform is funded by the Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research together with important stakeholders of economy and academia (Banthien and Senff, 2017, p. 144). The Federal Ministry of Education and Research has already planned and financed over 470 million EUR to support the research on Industry 4.0 (Federal Ministry of Education and Research, 2019). The aim is to follow up on the work the associations have prepared already. Five Working Groups have been established within the platform focusing on the following: Reference Architectures, Standards and Norms, Technology and Application Scenarios, Security of Networked Systems, Legal Framework, Work, Education and Training and Digital business models in Industry 4.0 (Plattform Industrie 4.0, 2019b). Furthermore, Platform Industry 4.0 is funding test bed scenarios where small and medium sized mechanical and plant engineering companies can test their latest developments in realistic environment (ibid.).

3.2.4 The Vision of Germany’s Industry 4.0

The core vision of the concept of Industry 4.0 is an intelligent, interconnected world within the Internet of Things and Services (Kagermann et al., 2013, p. 23). It is not a closed system but represents a symbiosis of key technologies such as CPS and the Internet of Things and Services (Bartodziej, 2017, p. 35 ff.). The center of Industry 4.0 is the Smart Factory (ibid.). It combines the complexity of Industry 4.0: humans, machines and resources communicate easily, and new intelligent infrastructures can be established (Kagermann et al., 2013, p. 23). Figure 4 visualizes how the Smart Factory connects the components of Industry 4.0.

Figure 4: The Smart Factory



Source: Own Source based on Kagermann et al., 2013, p. 23

Production in a Smart Factory unites vertical connection of products and systems and engineering across the value chain with horizontal integration through value networks (Kagermann et al., 2013, p. 23). The three characteristics needed to achieve the goal of a dual CPS strategy (see Chapter 3.2.2.1). Horizontal integration through value networks is defined as the use of various IT systems in different stages of production processes within a company but also between several different companies (value networks) (Bartodziej, 2017, p. 36). Vertical integration and networked manufacturing systems is the connection between IT systems and different hierarchy levels as for example production management and manufacturing and execution level (Kagermann et al., 2013, p. 24). Moreover, appropriate IT systems providing end-to-end support to the entire value chain are needed (Bartodziej, 2017, p. 36). Germany is taking action to implement the dual strategy by doing further research in the previously named areas (Kagermann et al., 2013, p. 10).

3.3 Seeking International Cooperation

The Industry 4.0 concept identifies the necessity of international cooperation (Kagermann et al., 2016, p. 29). It is a key feature for the Federal Government and the Platform Industry 4.0 for overcoming challenges of digitalization by working together across borders (Plattform Industrie 4.0, 2019c). The following bilateral and multilateral cooperations have been established: German-Chinese intergovernmental cooperation (see Chapter 5.3.4), German-Italian intergovernmental cooperation, France – *Alliance Industrie du Futur* and the cooperation with the Industrial Internet Consortium in the U.S.A (ibid.). The Platform Industry 4.0 and the Industrial Internet Consortium created a map to ensure future interoperability of the reference architecture models RAMI40 and the Industrial Internet Reference Architecture (see Chapter 4.3), created by the Industrial Internet Consortium in the United States (Plattform Industrie 4.0, 2019a). Standardization plays an important role in international cooperation for Germany (ibid.).

4 U.S.A

4.1 Manufacturing Industry

The United States is one of the most industrialized countries in the world. The country's manufacturing industry has been an important factor leading to a positive development. Nevertheless, the U.S. have had a challenging decade between 2000 and 2010 in the manufacturing industry. For most of the time between 1965 and 2000, the U.S. has constantly employed 17 million people in the manufacturing industry (Bonvillian, 2017, p. 6). Between 2000 and 2010 the sector faced huge job losses and the number of people employed in the industry shrunk to 12 million (ibid.). Furthermore, this led to a decline in manufacturing share of GDP from 27 % to 12 % (ibid.). There have been several reasons leading to the negative trend. One aspect is the increased dependence on imports of machinery products since 2002, as a result of relocation of production to other regions in the world (Kagermann et al., 2013, p. 72). Sectors affected by globalization such as textile and furniture (lower wages outside of the U.S.) have suffered the most job losses due to relocation (Bonvillian, 2017, p. 6). Since 2010 a positive trend in the manufacturing industry is visible. Domestic demand as well as demand for export of goods from the U.S are permanently increasing (Kagermann et al., 2013, p. 72). "Reshoring" and "Insourcing Boom" are buzzwords used frequently in this turnaround which implies bringing back manufacturing to the U.S. (ibid.). The U.S. Government plays an important role in this process as focus is to bring back production to the U.S. in order to create more jobs (Kagermann et al., 2013, p. 74). In 2015 the United States were able to increase the number of people employed in the manufacturing industry to 12.3 million (Bonvillian, 2017, p. 6). The industry is also supporting jobs of 56.9 million people (Giffi et al., 2016, p. 3). By taking this into account, the manufacturing industry is the industry generating the most jobs.

Additionally, this area of industry started to create higher income jobs than any other industry in the U.S. (Giffi et al., 2016, p. 3). In 2016 the Global Manufacturing Competitiveness Index (in the following GMCI) which has been prepared by Deloitte Touche Tohmatsu Limited (DTTL) Global Consumer and Industrial Products Industry Group and Council on Competitiveness stated expectations which predict an even greater future for the United States. The study builds upon prior GMCI studies published in 2010 and 2013 and show the influence of manufacturing on the economy (Deloitte, 2019). During the study manufacturing executives were asked to rate overall manufacturing competitiveness of 40 countries (Giffi et al., 2016, p. 3). The table below demonstrates the outcome of the survey on trending rank and future forecast of manufacturing powerhouses.

Table 1: Global CEO survey: Manufacturing powerhouse rank trending and future forecast

	2010	2013	2016	2020*
#1	China	China	China	U.S.A
#2		Germany	U.S.A	China
#3		U.S.A	Germany	Germany
#4	U.S.A		Japan	Japan
#5				
#6	Japan		United Kingdom	
#7				
#8	Germany			United Kingdom
#9				
#10		Japan		
…				
#15		United Kingdom		
…				
#17	United Kingdom			

Source: Own Source based on Giffi et al., 2016, p. 5

Based on the projected ranks for 2020, the United States are predicted to overtake China and reaching the first position by end of this decade (Giffi et al., 2016, p. 1). The United States have regularly made investment in development of advanced manufacturing technologies and it is predicted this will pay off in 2020 (ibid., p. 5).

4.2 U.S.A and the fourth Industrial Revolution

In the United States the term Industry 4.0 is mainly known by the terms “Internet of Things”, “Smart Production” or “Industrial Internet” (Kagermann et al., 2016, p. 53). The scope of the term is much broader in the United States. A particular interest is the context of optimizing production chains and developing technical innovations as well as establishing new business models and “Smart Services” in connection with the Industrial Internet (ibid.). The Industrial Internet involves the integration of Internet of Things and Services and Cyber-Physical Systems into industrial processes (Arnold, 2017, p. 44). Furthermore, it enables intelligent industrial operations by using advanced data analytics and it is redefining the landscape for businesses and individuals (Industrial Internet Consortium, 2019d).

As analyzed earlier the U.S. faced the loss of industrial jobs through the relocation of factories to low-wage countries. The U.S. government has put an emphasis on reindustrialization in order to keep up with international competitors. Consequently, the U.S. government is committed to increasingly promote modern production technologies (Heilmann et al., 2016, p. 44). The U.S. advantage is to be found in the high-tech and software industry and particular the internet is playing an increasingly important role by having a lasting influence on the manufacturing industry (Shubin and Zhi, 2016, p. 102).

4.3 Industrial Internet Consortium

In contrast to the German “Industry 4.0” concept, the United States have established a similar organization founded by members from industry and not involving the government (Müller and Voigt, 2018, p. 660). The organization is called “Industrial Internet Consortium” (in the following IIC) and was founded in March 2014 by AT&T, Cisco, General Electric, IBM and Intel (Pike, 2017, p. 149). By taking a look at the founding members one realizes they represent all aspects of what Industry 4.0 stands for: production, communication and information technology (Heilmann et al., 2016, p. 47). It is a not-for-profit organization with an open membership and has as of 2017 over 250 members from 26 countries (ibid.). Management activities of IIC have been transferred to the Object Management Group (in the following OMG), an internationally recognized organization which develops standards for cross-system and object-oriented programming (Sendler, 2016c, p. 77). Therefore, fast international expansion of IIC is not surprising. IIC is a leading organization when it comes to transforming business and society in terms of the Industrial Internet of Things (in the following IIoT) (Industrial Internet Consortium, 2019a). The mission is to provide IIoT in which systems and devices are connected in a securely manner (ibid.). IIC delivers a large view on the Industrial Internet. The focus is not only on manufacturing but also on energy, healthcare, public sector and transportation (Slama et al., 2016, p. 200). Through the formation of the “Industrial Internet Consortium” barriers of technology silos shall be eliminated to establish better access to big data and improve integration of physical and digital world (Pike, 2014). A more connected world and interoperability is aimed at by creating industry use cases and testbeds for real-world applications, providing case studies and standards to simplify the usage of connected technologies and influencing the standardization process for internet and industrial systems (ibid.). Furthermore, exchanging ideas, practices, lessons learned and insights in open forums and boosting confidence in regard to security of innovative approaches are encouraged by IIC (ibid.). Testbeds are one very essential tool which characterizes the work of IIC. Testbeds are member-sponsored innovation projects supporting the goals of IIC and aim to deliver solutions (Slama et al., 2016, p. 200). It is a controlled experimentation platform exploring untested technologies working together and can take up to 60 months duration (Industrial Internet Consortium, 2019c). Moreover, IIC works in organized work groups and has established a reference architecture, the “Industrial Internet Reference Architecture (in the following IIRA) (Sendler, 2016c, p. 78). IIRA serves two primary purposes. It is the foundational framework for all technical documents and activities and provides guidance in the development, documentation, communication and deployment of IIoT systems (Lin et al., 2017, p. 6). There are no quantified objectives set by the IIC, it is rather a platform whose purpose is to enable industry to use the Industrial Internet as broadly as possible (Heilmann et al., 2016, p. 47).

The Industrial Internet Consortium’s main funding is provided by membership fees. There are different types of memberships which are illustrated in table 2.

Table 2: IIC Membership Fees

Membership Level	Annual Cost (in USD)
Founding Members of the IIC	150,000
Contributing Members	150,000
Large Industry (annual revenues over USD 50 million)	50,000
Small Industry (annual revenues under USD 50 million)	5,000
Academia and Non-Profit	2,500
Government	12,500

Source: Own source based on Industrial Internet Consortium 2019b

Each membership level has different member benefits and therefore also different annual costs. They differentiate each other by the number of seats and or the opportunity to gain a seat in the Steering Committee and the number of meeting passes (Industrial Internet Consortium 2019b). In general, a membership entitles each member to have a voice in setting standards, best practices and processes of the Industrial Internet (ibid.). Furthermore, the U.S. government supports the IIC with an annual amount of a USD 100 million for research and development in the field of CPS (Sendler, 2016c, p. 77). Nevertheless, there is very little interference by the government in the IIC (ibid.).

4.4 Advanced Manufacturing

The relocation of production plants back in the U.S. have been a focus topic for many years now. Already in 2011 former U.S. president Obama created the “Advanced Manufacturing Partnership” (in the following AMP) consisting of members of science, economy and politics to improve the competitiveness of the United States (Kagermann et al., 2013, p. 74). The program aims at supporting innovations in the manufacturing sector, securing skilled workers and improving the business environment (Heilmann at al., 2016, p. 47). Furthermore, companies, the government and other stakeholder shall be enabled to identify new manufacturing technologies (ibid.). In order to do so, Obama’s government has released additional funds for research and development in the context of production (Kagermann et al., 2013, p. 74). Different public and private research initiatives are supported by AMP and every initiative has its own specialization in researching new technologies (Heilmann et al., 2016, p. 47).

In October 2018 the Subcommittee on Advanced Manufacturing, Committee on Technology of the National Science & Technology Council published the “Strategy for American Leadership in Advanced Manufacturing”. The strategy includes three overall objectives for advanced manufacturing in the United States: Develop and Transition New Manufacturing Technologies; Educate, Train, and Connect the Manufacturing Workforce and Expand the Capabilities of the Domestic Manufacturing Supply Chain- Furthermore, the strategy also recaps the progress made in achieving the objectives from 2012, when Obama introduced the AMP. Under each goal several strategic objectives have been identified and moreover each objective has a set of technical priorities including actions and outcomes to be accomplished (National Science & Technology Council, 2018, p. 8). The first goal “Develop and Transition New Manufacturing Technologies” addresses the topic of Industry 4.0 the most. Its objectives are to capture the future of intelligent manufacturing systems, develop world-leading materials and processing technologies, assure access to medical products through domestic manufacturing, maintain leadership in electronics design and fabrication and strengthen opportunities for food and agricultural manufacturing (ibid.). Table 3 takes a closer look at each objectives’ technical priorities.

Table 3: Develop and Transition New Manufacturing Technologies: Objectives and technical priorities

Objective	Technical Priorities
Capture the Future of Intelligent Manufacturing Systems	• Smart and Digital Manufacturing • Advanced Industrial Robotics • Infrastructure for Artificial Intelligence • Cybersecurity in Manufacturing
Develop World-Leading Materials and Processing Technologies	• High-Performance Materials • Additive Manufacturing • Critical Materials
Assure Access to Medical Products through Domestic Manufacturing	• Low-Cost, Distributed Manufacturing • Continuous Manufacturing • Biofabrication of Tissue and Organs
Maintain Leadership in Electronics Design and Fabrication	• Semiconductor Design Tools and Fabrication • New Materials, Devices, and Architectures
Strengthen Opportunities for Food and Agricultural Manufacturing	• Processing, Testing, and Traceability in Food Safety • Production and Supply Chain for Food Security • Improved Cost and Functionality of Bios-Based Products

Source: Own Source based on National Science & Technology Council, 2018, pp. 8 - 17

By analyzing table 3 it becomes clear the objective “Capture the Future of Intelligent Manufacturing Systems” focuses on technical priorities which are an integral part of the fourth industrial revolution. Therefore, a closer look shall be taken at each priority and its suggested actions.

Smart and Digital Manufacturing refers to seamless integration from design to product manufacturing by using sensors, controls, software platforms as well as a computer-based system (National Science & technology Council, 2018, p. 9). For the next four years, government has planned the following actions in order to achieve the goal:

> “Facilitate a digital transformation in the manufacturing sector by enabling the application of big data analytics and advanced sensing and control technologies to a host of manufacturing activities. Prioritize support for real-time modeling and simulation of production machines, processes, and systems to predict and improve product performance and reliability; mine historical design, production, and performance data to reveal the implicit product and process know-how of the expert designers who created them. Develop the standards that will enable seamless integration between smart manufacturing components and platforms.” (ibid.)

Moreover, Advanced Industrial Robotics are seen to be an advantage for reducing manufacturing costs and at the same time beneficial to workers mental and physical stress (ibid.). The government supports the progress of Advanced Industrial Robotics by promoting development of new technologies, adoption of robotics and safe, efficient human-robot interactions (ibid., p. 10).

A key to empowering the Industrial Internet of Things is the incorporation of cloud computing, data analytics and computational modeling with Artificial Intelligence (ibid.). A huge set of data is needed for machine learning, hence a secure infrastructure for companies needs to be present (ibid.). Consequently, government is focusing on developing standards, providing availability and accessibility, while keeping data secure and respecting intellectual property rights (ibid.). Additionally, research and development will be done in the field of data access, confidentiality, encryption and risk assessment for U.S. manufacturers (ibid.).

The last technical priority is the topic of Cybersecurity in Manufacturing. By developing standards, tools and testbeds, U.S. government moves manufacturing industry towards better cybersecurity (ibid.).

5 China

5.1 Manufacturing Industry

In the past decade China has become a leader in manufacturing and one of the largest economic powers (Li, 2017, p. 66). The country did undergo a continuous growth over the past 30 years and became in 2010 the second largest economy in the world (GDP USD 5.7 trillion) (Deloitte China Research and Insight Centre, 2011, p. 3). The improvement of the manufacturing industry in China was mainly contributing to this positive development (ibid.). Whereas by 1990 Chinas manufacturing industry only accounted for 2.7% of the global manufacturing industry (9th place worldwide), the country was able to increase its share in 2010 to 19.8%, making it the largest manufacturing industry in the world (Müller and Voigt, 2018, p. 660). In 2015 China was producing or assembling 28% of the world's automobiles, 41% of the world's ships, 80%+ of the world's computers, 90%+ of the world's mobile phones, , 80% of the world's air-conditioners, 24% of the world's power and half of the world's steel, indicating its high productivity and major share in the manufacturing industry (European Union Chamber of Commerce, 2017, p. 2). In contrast to other industrialized countries China had to skip some steps of the third industrial revolution in order to achieve this stage and fast development (Müller and Voigt, 2018, p. 660). Therefore, it is difficult to actually evaluate where Chinas industry is currently at. Some argue China is on the way from Industry 2.0 (mass production/assembly line) to Industry 3.0 (computer-based automation) (Sendler, 2016d, p. 86). Chinas manufacturing industry has a few global players such as Huawei and Haier which are already in possession of highly automated production plants (Kagermann et al., 2016, p. 5). Furthermore, China does not need to hide when it comes to robotics, construction of high-speed trains or aerospace industry (Sendler, 2016d, p. 86). This part of the industry is already way ahead of many companies in the U.S.A. and Germany and can easily keep up with the big players in Silicon Valley (ibid.). When taking a look at the electrical industry, which includes suppliers of components, information and communication technology, automation, household appliances, energy technology, consumer electronics, lighting and electromedicine, China is taking the lead (ibid.). In 2013 more than 24 million people have been employed in this industry globally, whereof 14.5 million were employed in China (ibid., p. 87). On the other hand, there is also a large number of SME's which are in many cases still on the threshold of computer-integrated production

(Kagermann et al., 2016, p. 5). The manufacturing sector is a very heterogenic industry and it is challenging when trying to characterize the stage of industrialization. Large parts of the industry are not even on the level of Industry 2.0, but rather in pre-industrial manufacturing, meaning not using any electric mass production on an assembly line that entered the Western world hundred years ago (Sendler, 2016d, p. 86). Leading to the conclusion, Chinese manufacturing is only partially automated but still far away from an overall digital value chain when taking into account the whole country (ibid., p. 89).

5.2 Technical Infrastructure

In the past two decades China experienced an increasing improvement in technical infrastructure, especially in terms of network infrastructure (Wu, 2018, para. 1). And the development is not stopping yet. China included to increase broadband penetration rate by 30 percent and its mobile broadband penetration rate by 28 percent (Wu et al., 2016, p. 8). They are aiming to achieve this goal by 2020 while doing research on more advanced technologies such as 5G and ultra-wideband (ibid.). The development China has gone through gets most visible by taking a look at the internet penetration rate. This rate marks the proportion of internet users to total population. In 2008 this rate had been at 8.5 % and increased to 45.8 % by 2013 (Nie et al., 2015, p. 1). By 2017 this number exceeded the 50 % mark with 55.8 % of the population (CNNIC, 2018). By comparing this number to the percentage of people living in cities which equals 59.15 % it can be concluded most of the people in cities do have excess to internet connection (World Bank, 2019). This is also due to the focus of establishing *smart* and *wireless* cities (Wu et al., 2016, p. 8). Furthermore, China overtook the U.S. in 2013 as being the world's largest Internet user (Nie et al., 2015, p. 1). At the end of 2015 China had 688 million Internet users and 620 million mobile Internet users (Wu et al., 2016, p. 18).

5.3 The Fourth Industrial Revolution in China

5.3.1. Made in China 2025

As it had been elaborated upon in the previous chapters, China has gone through a big economic change. The fast development led to China becoming one of the world's leaders. Villages became cities of millions and the country developed into an industrialized nation (Sendler, 2016d, p. 83). Four of the ten most populated cities of the world are located in China (ibid.). New opportunities are given but also challenges have emerged. The manufacturing industry is facing an increase in labor and material costs (Li, 2017, p. 67). Moreover, constraints in resources and environment are rising and at the same time foreign direct investment flows and export growth are decreasing (ibid.). Therefore, it was fundamental for China to find a solution in order to start rethinking their manufacturing strategy (ibid.). The government has identified the key to further growth in development of the manufacturing industry (Shubin and Zhi, 2016, p. 92). Consequently, Chinese government has taken measures to reach that goal. In May 2015 Chinese State Council released the initiative Made in China 2025 which aims at enhancing the Chinese industry (Müller and Voigt, 2018, p. 660). The initiative is China's 10-year plan for transforming labor intensive production to knowledge intensive manufacturing (Li, 2017, p. 67). The Made in China 2025 plan identifies nine focus tasks: improving innovations, integration of technology and business, strengthening the industrial base, promotion of Chinese brands in the world, environmentally friendly production, promotion of breakthroughs in ten major industrial sectors, restructuring of manufacturing sector (producing high quality products), promotion of service-oriented producers and service providers; and internationalization of production (Sendler, 2016d, p. 84). The following are the ten major industrial sectors China wants to focus on: new information technologies, high-end numerical control machinery and automation, aerospace and aviation equipment, maritime engineering equipment and high-tech vessel manufacturing, rail equipment, energy-saving vehicles, electrical equipment, new materials, biomedicine and high performance medical apparatus and agricultural equipment (State Council of People's Republic of China, 2017). Furthermore, the program targets replacing reliance on foreign technology imports (Institute for Security & Development Policy, 2018, p. 2). Chinese companies shall be able to compete on a domestic as well as on a global level when it comes to manufacturing processes, quality, technological innovation and machine learning (ibid.).

The Made in China 2025 initiative is the response to Germany's Industry 4.0 concept and it is seen as a booster for China's economic growth (Li, 2017, p. 67; Sendler, 2016d, p. 85). 150 experts had worked out the plan for two and a half years and it is supposed to transform China into a leading manufacturing power (ibid., pp. 83 - 84).

5.3.2 Five Initiatives

As it has been analyzed before, the Chinese plan of Made in China 2025 focuses on nine tasks and on ten major industrial sectors. Furthermore, the initiative was planned for the market to take the lead while government only provides guidance (Shubin and Zhi, 2016, p. 96). That is why the Chinese government introduced the five most important projects (ibid.). The five initiatives are illustrated in table 4 by name of initiative as well as details on the projects.

Table 4: Five National Initiatives

	Initiative	Details
1	R&D and Innovation Centers	Focusing on areas such as next-generation ICT, smart manufacturing, new materials, additives and pharmaceuticals
2	Smart Manufacturing Projects	Supporting and leading companies in setting up smart manufacturing
3	Industrial Bases	Stimulate the development of core industrial components, techniques, materials and production technology
4	Green Manufacturing Projects	Energy efficiency, environmental protection, resource usage, re-manufacturing and low-carbon technologies
5	High-end Equipment Manufacturing Projects	Projects in aerospace, rail, new-energy vehicles, marine, smart grids, high-end machine tools, nuclear and medical equipment

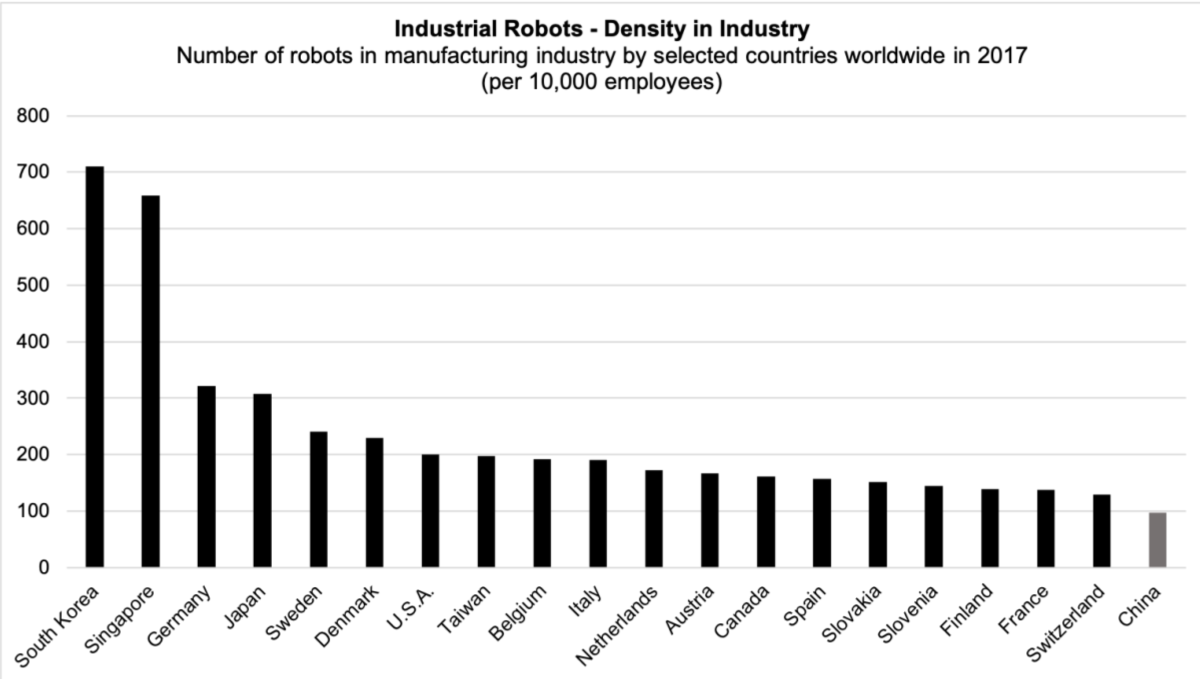
Source: Own Source based on China-Britain Business Council, 2016, p. 12.

The first project aims to concentrate on the establishment of R&D and Innovation centers. Goal is to establish 15 national manufacturing innovation centers by 2020 and increase the number to 40 by 2025 (China-Britain Business Council, 2016, p. 12). Secondly, an emphasis is put on Smart Manufacturing Projects. Smart Manufacturing goes hand in hand with digitalization and artificial intelligence and is supposed to higher the standard of manufacturing (Shubin and Zhi, 2016, p. 97). Moreover, the intention is a decrease in operation costs, production time and defect rates of 50% by 2025 (China-Britain Business Council, 2016, p. 12). The third initiative concentrates on establishing four new research centers known as “Four Bases” (ibid.). By 2025 those establishments shall contribute to self-sufficiency for 70% of core components and materials in key sectors (ibid.). China’s economic development is limited due to resource shortage. Hence, the Chinese State Council has included Green Manufacturing Projects in the plan. The goal is to save natural resources by reducing energy (73% of the countries’ energy consumption is used by industry) and emission (Shubin and Zhi, 2016, p. 97). The fifth focus initiative is High-End Equipment Manufacturing Projects. Through research and development China wants to achieve an increase of standards in the context of plant engineering (Shubin and Zhi, 2016, p. 97).

5.3.3 Smart Factory China

Smart Manufacturing plays an important role within Made in China 2025. Especially since China, in comparison to other industrialized nations, does not have the best starting position. It has been identified, it is not clear where China stands within the industrialization process. Clear is, automation and digitalization in China's industry is lower than in other industrialized countries (Wübbeke et al., 2016, p. 11). As the following figure 5 illustrates, China falls behind when looking at the number of industrial robots used in manufacturing industry.

Figure 5: Density of Industrial Robots in Manufacturing Industry



Source: Own source based on IFR (2018b)

By 2017 only 97 industrial robots per 10,000 employees were being used in China (IFR, 2018b). Whereas the number of sales of industrial robots in China is very high. China has been world's leader in sales for several years already, leaving Japan, South Korea, U.S.A and Germany behind and the forecast for 2021 looks even better (IFR, 2018a). Therefore, it is not surprising China sees it as an important task for smart manufacturing to focus on high-end computerized numeric control machine tools, advanced IT and industrial robots (Wübbeke et al., 2016, p. 17). In addition, the plan aims at advancing production technology across all industries: large- and small-scale, state-owned as well as private enterprises (ibid.).

Deloitte (2018, p. 1) has identified five focus areas among Chinese industrial enterprises in terms of usage of smart manufacturing: digital factory, in-depth extraction of equipment and user value, IIoT, business model restructuring and artificial intelligence. Furthermore, there are additional technologies of interest China is concentrating on which include industrial software, sensor communication technology, IoT, and big data analytics.

Chinese Government is giving great support in order to achieve the previously named goals in the context of smart manufacturing. Several funds have been established to secure the financial needs of the program (Wübbeke et al., 2016, p. 7). The Advanced Manufacturing Fund amounts to 20 billion CNY (2.7 billion EUR) and adds to the foundation of China's industrial future (ibid.).

5.3.4 International Cooperation

For implementing the strategy Made in China 2025, China is also looking out for cooperation on an international level. One main player for cooperation is Germany. In 2015 China and Germany signed an official document stating to intensify cooperation between German and Chinese enterprises in the area of Germany's Industry 4.0 and Chinese Made in China 2025 (Bundesministerium für Wirtschaft und Energie, 2015, p. 1). This cooperation is also known by the name "Shaping Innovation together!" and includes following aspects which were presented by the Chinese prime minister: emphasis on digitalization of industry (Industry 4.0) for further development of German and Chinese economy, country dialogue to exchange information on Industry 4.0, working close together on standardization issues and high level of cooperation in areas of Mobile Internet, Internet of Things, Cloud Computing and Big Data (Shubin and Zhi, 2016, pp. 101 – 102). Chinese Government sees a very positive influence in the cooperation between the two nations. Not only will cooperation add positively to production of high-quality products, but also to the happiness of the people in Germany and China (ibid.).

5.3.5 Internet Plus Strategy

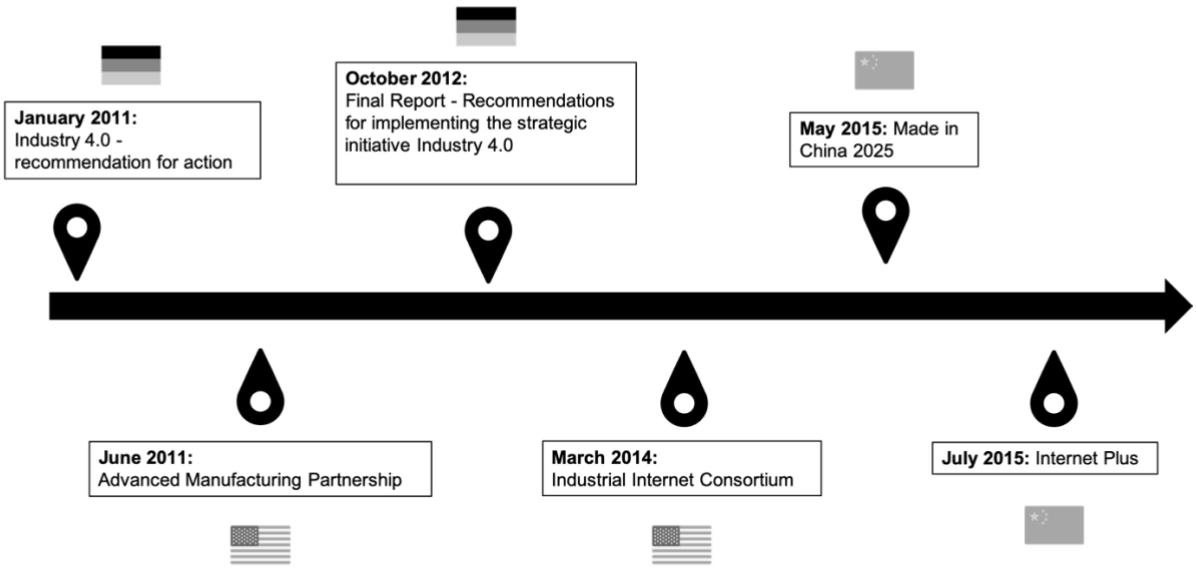
While Made in China 2025 concentrates on the vertical level of the manufacturing industry, China has developed a program to serve the horizontal level as well, which puts focus on the integration of internet in traditional industries (Shubin and Zhi, 2016, p. 114). In July 2015 the country introduced its Internet Plus strategy. In comparison to the total top-down approach of Made in China 2025, Internet Plus is also supported by initiatives from internet enterprises (bottom-up) (Wübbeke et al., 2016, p. 20). The strategy includes to integrate mobile internet, cloud computing, big data and the Internet of Things with modern manufacturing (Xinhua, 2015). While the focus of Made in China 2025 is put on digitalization of manufacturing sector, Internet Plus is aiming to transform the industry by using digital technologies (Wu et al., 2016, p. 9). Internet Plus identifies a total of eleven focus topics: Start-up and Innovation, Cooperative Manufacturing, Modern Agriculture, Intelligent Energy, Inclusive Finance, Advantageous Services for the Population, Highly Efficient Logistics, E-Commerce, Comfortable Transport, Green Ecology and Artificial Intelligence (Shubin and Zhi, 2016, p. 114). Even though Internet Plus is a bottom-up based initiative, Chinese Government supports it by lowering market entry barriers of Internet-Plus-Products as well as providing financial support to key projects related to the policy (Xinhua, 2015). Internet Plus and Made in China 2025 are two separate programs. At the same time the two initiatives are supporting and both benefitting from each other (Shubin and Zhi, 2016, p. 114).

6 Germany, U.S.A and China in Comparison

6.1 Introduction

In the previous chapters the three countries and their initiatives in the context of Industry 4.0 have been introduced and explained in detail. Based on the previous findings a comparative analysis can be made taking into consideration the concept of Industry 4.0, Advanced Manufacturing Partnership, Industrial Internet Consortium, Made in China 2025 and Internet Plus. As elaborated upon the term Industry 4.0 has its origins in Germany where it was first introduced in 2011 (Sukhodolov, 2019, p. 5). Taking this fact into account, it is not surprising Germany was the first mover of establishing a concept connected to the fourth industrial revolution as visible in figure 6.

Figure 6: Timeline Introduction of Initiatives



Source: Own Source based on Sukhodolov, 2019, p. 5; Kagermann et al., 2013, p. 74 ff.; Pike, 2017, p. 149; Müller and Voigt, 2018, p. 660; Wübbeke et al., 2016, p. 20

Second was the U.S. with its introduction of AMP in 2011 and IIC in 2014 (Kagermann et al., 2013, p. 74; Pike, 2017, p. 149). And the last country introducing its initiatives towards Industry 4.0 was China in 2015 with Made in China 2025 and Internet Plus (Müller and Voigt, 2018, p. 660; Wübbeke et al., 2016, p. 20). All concepts are strategic initiatives aiming at influencing the world's economic situation and improving the respective national industrial structures (Fu, 2017, p. 166). There are similarities and differences in the previously named concepts which will be further discussed in the following subchapters.

6.2 Analyzing Implementation of Concepts

6.2.1 Overall Strategic Goals

The strategic goals of each initiative will be further examined and compared in the following. Germany sees Industry 4.0 as a chance to keep its competitiveness in the manufacturing industry and aims at becoming the leading provider in the new market (Kagermann et al., 2011, p. 2). The United States overall goal of IIC is the provision of IIoT to create a connected world (Industrial Internet Consortium, 2019a). Furthermore, AMP aims at securing skilled workers, supporting innovations in the manufacturing sector and improving the business environment to become competitive in the sector again (Kagermann et al., 2013, p. 74). China's goal is quite similar. By transforming labor intensive production to knowledge intensive manufacturing China wants to become the leading manufacturing nation (Sendler, 2016d, pp. 83 – 84).

By comparing the overall strategic goals, it can be noticed all three countries aim for improvements in manufacturing industry to become the most competitive leader in their field. All three countries want to achieve the overall goal thru the implementation of Industry 4.0 initiatives. With this goal in mind Germany, U.S.A and China established those concepts. The implementation of concepts is being influenced by different starting positions, challenges and strengths each country is facing.

6.2.2 Starting Position

Three countries in three different starting positions are confronted with the fourth industrial revolution. Germany, U.S.A and China have all gone through different phases of development when it comes to the manufacturing industry. Whereas Germany and U.S.A have closed up with Industry 1.0, 2.0 and generally with Industry 3.0, China is in a different starting position (Fu, 2017, p. 168). The starting position is best to be defined by taking a closer look at the challenges and strengths each country is confronted with. Challenges and strengths are summarized in table 5.

Table 5: Strengths and Challenges

Country	Strengths	Challenges
Germany	Stable Manufacturing Industry	Keep up with innovations
	High Automation in Manufacturing Industry	Technical Infrastructure
USA	High-Tech and Software Industry	Bringing back Manufacturing
	Regular Investments in Manufacturing Technologies	Dependence on Imports
		Technical Infrastructure
China	High Productivity	Low Automation in Manufacturing
	Electrical Industry	Heterogenic Industry
	Technical Infrastructure	Constraints in Resources and Pollution
	Fast Development	Product quality and awareness abroad
		Increasing Labor and Material Costs

Source: Own source based on Kagermann, 2015, p. 23; Kagermann et al., 2013, p. 72; IFR, 2018b; OECD, 2019; Sendler, 2016d, p. 86; Li, 2017, p. 67

As examined before, China stands somewhere between Industry 2.0 and 3.0 in the majority of cases. As it has gone too fast through development, a heterogenic industry emerged with low automation in manufacturing. On the other hand, the fast development can be seen as a strength as China is able to take fast actions. Furthermore, China is confronted by an increase in labor and material cost as well as constraints in resources (Li, 2017, p. 67). Nevertheless, China is able to keep up with Germany and the United States. For decades China has been the factory of the world with its capability of high production (European Union Chamber of Commerce, 2017, p. 2). Regardless, the quality and reputation of products is not at the point where it should be. China's technical infrastructure is well developed (world's largest internet user) and also China's electrical industry is more than advanced (Nie et al., 2015, p. 1). While China has made big steps forward, the U.S.A faced job losses due to relocating its production plants to low-wage countries and needs to focus on bringing manufacturing back to the U.S. (Bonvillian, 2017, p. 6). By doing so, the dependence on imports could decrease. The country has a strong advantage in terms of software and high-technology and made regular investments in manufacturing technologies but at the same time lacks in technical infrastructure (Kagermann et al., 2016, p. 53; Sendler, 2016c, pp. 79 - 80). On the contrary, Germany stayed stable in the past decade by taking into account their manufacturing industry. It is Germany's backbone and through knowhow, IT and high automation one of the most competitive industry locations (Rojko, 2017, p. 80). A challenge Germany faces is to keep up with the innovations in order to stay competitive (Kagermann, 2015, p. 24). Additionally, the technical infrastructure is not as good developed as in China and the U.S. in terms of internet connections (OECD, 2019). Therefore, an emphasis is put on establishing a comprehensive broadband infrastructure for industry. By comparing the different starting positions, it becomes clear Germany, U.S.A and China are taking off from different positions towards Industry 4.0. U.S.A. and Germany are well prepared considering their level of industrialization. In contrast, China has to master Industry 2.0, 3.0 and 4.0 while at the same time restructuring its traditional industry.

6.2.3 Execution

As an answer to Germany's Industry 4.0 strategy U.S.A and China came up with their own initiatives addressing the topic. Table 6 highlights the differences in execution and support of the initiatives.

Table 6: Comparing Execution

Initiative	Country	Funding/Support
Industry 4.0	Germany	Government
Industrial Internet Consortium	U.S.A	Companies
Advanced Manufacturing Partnership	U.S.A	Government
Made in China 2025	China	Government
Internet Plus	China	Government /Companies

Source: Own Source based on Kagermann et al, 2016, pp. 37 ff.

In Germany the strategy has been triggered by a group of experts and was immediately picked up by the Federal Government (Ślusarczyk, 2018, p. 233). In contrast, the U.S.' organization IIC was founded by major companies representing the aspects of Industry 4.0 and financed by its members (Heilmann et al., 2016, p. 47). Implicating, the topic of Industry 4.0 is mostly important in expert circles and market driven. A program has been established by the Government as well, but it is not solely focusing on addressing the challenges of Industry 4.0 (National Science & Technology Council, 2018, p. 8). China's Made in China 2025 and Internet Plus strategy were both launched by the Government and enjoy their financial support (Wübbeke et al., 2016, p. 20). Though Internet Plus pursues a mixture of Government and Company support (Wübbeke et al., 2016, p. 20). Concluding, Germany is aiming at a top-down approach when realizing Industry 4.0 whereas the U.S. development is dominated by a bottom-up approach. China's approach is on the one hand top-down but has features of bottom-up. Taking a closer look at the funds provided, the Chinese Government invests the most in the future of the country's manufacturing industry. One may argue, this is due to China lagging behind in manufacturing industry. Nevertheless, it is also the country with the biggest population (IMF, 2019). The IIC is dependent on its membership fees. By charging fees IIC's entry barriers are higher in participating in the program than in Germany and China. Even though the amount to be paid depends on the size of the company, only big players gain full access to all services (Industrial Internet Consortium, 2019b). Small and medium sized enterprises could be put off for the long term and face a lot of pressure to keep up (Kagermann et al., 2016, p. 56).

Germany and the U.S. both rely on knowledge-exchange through Working Groups to execute their strategies (Kagermann et al., 2013, p. 48; Pike, 2014). Additionally, research and development, discussions and best-case scenarios shall facilitate development in Industry 4.0. However, it should be pointed out that Germany's dialogue-oriented approach often acts as a deterrent to many companies (Kagermann et al., 2016, p. 38). Consensus building is feared to take too long since too many parties (politics, science experts and companies) are involved (ibid.). The German way of executing the strategy is very theoretical (ibid., p. 39). The IIC provides fast and pragmatic solutions and was able to win many international companies for itself through this characteristic (Heilmann et al., 2016, p. 47). China concentrates on straightforward quantifiable objectives to achieve results (China-Britain Business Council, 2016, p. 12). Germany's Industry 4.0 and IIC do not set quantifiable objectives (Heilmann et al., 2016, p. 47). They are rather platforms following the purpose of enabling the use of Industry 4.0 technology (ibid.)

6.2.4 Focus

Subchapter 2.2 highlighted the complexity of the term Industry 4.0 and the fact a generally accepted definition does not exist (Bauer et al. 2014, p. 18). It is the fourth industrial revolution, a new stage in organization and control of value chain (Sendler, 2016a, p. 17). The unprecise definition of the term as well as the different starting positions of the three countries led to differences in areas of focus. Germany as the pioneer of Industry 4.0 is following the strategy of utilizing horizontal integration through value networks, end-to end digital integration and vertical integration and networked manufacturing (Kagermann et al., 2013, p. 6). Recommendations for implementing the strategy have been given and key areas have been identified. Germany puts focus on establishing standards to create interoperability between Industry 4.0 systems (Heilmann et al. 2016, p. 29). The adaption of production processes to meet the requirements are essential at this point and shall lead to the smart factory. This marks the center of Industry 4.0 where all components interact and a symbiosis of key technologies is represented (Bartodziej, 2017, p. 35 ff.). Furthermore, the strategy also addresses the social changes in the new working environment of Industry 4.0 (Kagermann et al., 2013, p. 6). Two key areas are focusing on the topic: work organization and design and training and continuing professional development (ibid.). Overall Germany puts great emphasis on the interconnectivity of software, hardware and human beings. On the other hand, the U.S. is defining Industry 4.0 slightly different. The focus lies on the Industrial Internet involving Internet of Things and

Services and Cyber-Physical-Systems into industrial processes (Arnold, 2017, p. 44). The traditional American industry shall be changed through the connectivity of systems (Fu, 2017, p. 168). In contrast to Germany, the vision does not only include manufacturing, but also energy, healthcare and transportation (Slama et al., 2016, p. 200). The U.S. has implemented a reference architecture for standardization, so did Germany (Sendler, 2016c, p. 78.). Standardization plays an important role for both countries. Their bilateral cooperation even aims at interoperability of the two reference architectures (Plattform Industrie 4.0, 2019a). There is a constant race for defining internationally accepted standards (Kagermann et al., 2016, p. 43). The country which is able to do this first can secure a competitive advantage for itself (ibid.). Testbeds are seen to be the best possibility for action to accelerate the development of norms and standards in Germany and the U.S.

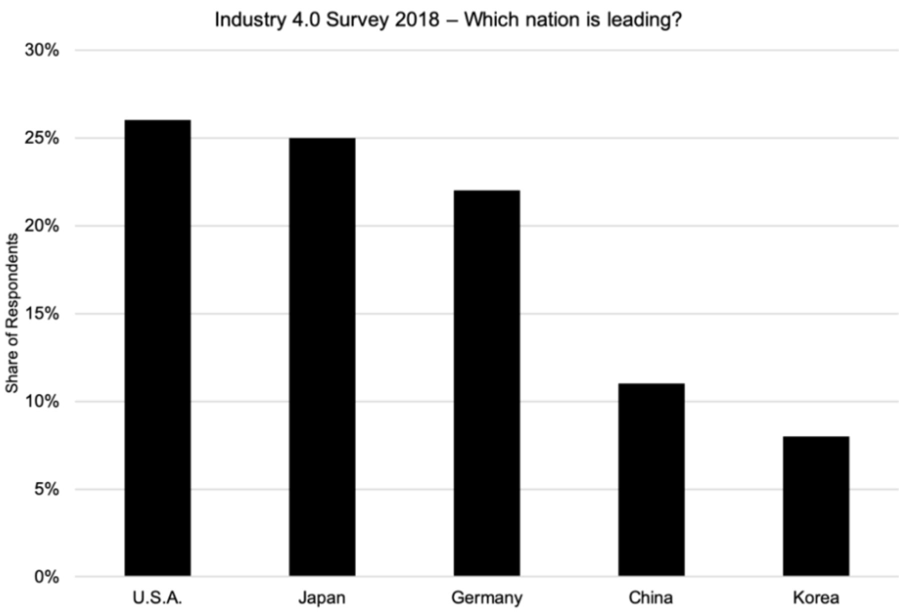
Whereas Germany focusses on combining software and hardware, the U.S. focuses by implementing IIC and AMP on software components. The center of attention is technology such as cloud computing, data analytics and AI. As analyzed before, the U.S. is strong in software technology industries (Shubin and Zhi, 2016, p. 102).

China has set its sights on achieving the goal by focusing on the total restructuring of its manufacturing industry (Fu, 2017, p. 168). Chinese products do not enjoy the good standing as compared to Germany and U.S. products. Quality and awareness are suffering ergo internationalization and the promotion of breakthrough innovations have become of great importance (Sendler, 2016d, p. 84). As well as Germany's Industry 4.0, China is enabling the vertical and the horizontal level of manufacturing with Made in China 2025 and Internet Plus (Shubin and Zhi, 2016, p. 114). Moreover, the international cooperation with Germany is a key component for China. As already mentioned, China wants to develop from an industry with high production volume to a strong performance industry with high-quality products (ibid., p. 104) Manufacturing industry is large (quantity) in China, while in Germany it is strong (quality) (ibid., 102). This characteristic identifies the perfect spearing partner for China. The concept Germany established built the fundament for Chinas strategies (Kagermann et al., 2016, p. 40). Hence, similarities are existing. Smart manufacturing building the core of Industry 4.0 in Germany is also essential for Chinas transformation.

6.3 Status Quo Implementation

Germany, U.S.A and China have all launched their strategies towards the fourth industrial revolution. But launching a strategy is not enough. It has to be monitored how successful the initiatives are and if progress is visible. Several studies have been carried out to check progress and to be able to define if the change is yielding results. A survey executed by Capgemini (IT service provider) in 2017 asked leading companies in several countries if smart factory processes are already introduced in the current manufacturing processes. In the U.S.A 54 % of the respondents answered they have ongoing smart factory processes (Capgemini, 2017, p. 7). In Germany the percentage of respondents was 46 % and in China 25 % (ibid.). Those answers fit to the results of the following figure 7 where the U.S.A has been identified as the leading nation in terms of implementation of Industry 4.0 (Bitkom, 2018).

Figure 7: Leading Nation 2018



Source: Own source based on Bitkom, 2018

Even though table 7 is just the result of a survey, the opinion behind is crucial. As examined before, the U.S. puts an emphasis on finding simple solutions, and predictions are the U.S. could become the leading powerhouse in manufacturing (Giffi et al., 2016, p. 5). China's share of ongoing processes in smart factory implementation are low compared to the other countries. Nevertheless, taking into account their starting position in manufacturing, it is not surprising. Considering the previously named results, Germany is in the midfield. All three countries still have a way to go and it will be interesting to observe the future progress.

7 Conclusion

7.1 Summary

Aim of the thesis is to compare and analyze the conception and implementation of Industry 4.0 and the initiatives in Germany, U.S.A and China. The term was first introduced in 2011 by Germany at the Hanover Fair. After its launch the term gained a lot of international attention as it is introducing a new era: the fourth industrial revolution. The first industrial revolution concentrated on mechanical manufacturing equipment, the second on electrically powered mass production and the third industrial revolution on automation of manufacturing by implementing electronics and information technology. The fourth industrial revolution aims at connecting the virtual and physical world via technologies such as AI, additive manufacturing and CPS. It is important to mention the fourth industrial revolution has not finished yet and is an ongoing process. The term Industry 4.0 and its suffix are also being used as a marketing tool. Therefore, one has to look closely into the concepts connected to the term. It is difficult to give a clear definition of Industry 4.0. The term is complex and consists of several technical components. As it is an ongoing process, new technologies are developed on a regular basis and change the definition and components. Cyber-Physical Systems, Internet of Things, Internet of Services and Smart Factory are reference components for Industry 4.0 and play an important role. Industry 4.0 is where digital and physical world are seamlessly interconnected, and products play an active role in the production process.

Germany has been the first mover by introducing its recommendation for action in 2011 and its final report in 2012. The manufacturing industry in Germany has always been one of the strongest and most stable. This advantage must be extended by keeping up with the innovations. Germany aims at a dual strategy: integrating information and communication technology as well as CPS technologies and products. It shall enable Germany to become a leading supplier of smart manufacturing technologies. Eight key areas for focus have been identified. The center of Germany’s vision of Industry 4.0 is the Smart Factory where humans, machines and resources communicate easily, and new intelligent infrastructures are being established.

The manufacturing industry in the U.S.A has had a different history than in Germany. Through relocation of production plants to low wage countries, the country faced job losses and became dependent on imports. The U.S.’s advantage lies in the high-tech and software industry. The government’s goal is to bring back manufacturing to the U.S. in order to become competitive again. Industry 4.0 is mainly known by Internet of Things, Smart Production or Industrial Internet in the United States. To serve the new era requirements a not-for-profit organization, the Industrial Internet Consortium, has been established by well-known production, communication and information technology companies. To become a member in the IIC one has to pay a member ship fee. The focus does not lie on manufacturing only but also on energy, healthcare, public sector and transportation. Moreover, the government introduced its Advanced Manufacturing Partnership aiming at supporting innovations in the manufacturing sector, securing skilled workers and improving the business environment.

China has a quite heterogenic manufacturing industry. The country did undergo a major development in the past 30 years and has become the factory of the world. Nevertheless, it is not clear where the industry is positioned at. It is somewhere between the second and third industrial revolution, though a few major players exist which can keep up with automation on an international level. China is facing the challenge of producing high quality products to create a better reputation and awareness for its products. An advantage for reaching that goal is Chinas well developed technical infrastructure in major cities and its research in new internet technologies. Furthermore, China is confronted with an increase in labor and material costs as well as constraints in resources. To overcome the challenges the Chinese Government introduced two initiatives: Made in China 2025 and Internet Plus. They are the response to Germany’s Industry 4.0 concept. Five initiatives have been identified as the most important projects within Made in China 2025 and eleven focus topics within Internet Plus to achieve the goal of becoming the leading manufacturing power. Smart manufacturing also plays a major role here where China relies on international cooperation with Germany.

Referring to the research question, the understanding of the term Industry 4.0 in Germany and China is quite similar whereas in the U.S.A the scope of the term is much broader and rather referred to as Industrial Internet. Overall, all three countries aim for improvements in the manufacturing industry and becoming the most competitive country by implementing strategies towards Industry 4.0. The differences in implementation go back to the countries starting positions. Each country faces different challenges which need to be overcome in order to reach the goal. Germany and the

U.S. are well prepared considering their level of industrialization whereas China has to master Industry 2.0, 3.0 and 4.0 at the same time. A top-down approach is used in Germany to execute the initiative. In the U.S. it is dominated by a bottom-up approach and in China it is a mixture of both. For implementation of the strategies funding needs to be provided. The three countries get financial support by the government, though the U.S. is very much dependent on the membership fees of the Industrial Internet Consortium. IIC is led by companies resulting in fast and pragmatic results. In contrast in Germany it takes longer using its dialogue-oriented approach. The concept in Germany is designed to have constant discussions and research and development but no quantifiable goals. The objectives in China are quantifiable and easy to monitor in the future. International cooperation is essential for China to manage the challenges the country is facing. For Germany it is crucial as well and the country has established several bilateral and multilateral agreements focusing on standardization.

To conclude, Germany’s initiative towards Industry 4.0 is mostly government driven and focusses on production processes with the overall aim of establishing smart factories. A mixture of software and hardware is in the foreground. The United States’ counterpart initiative is market-driven and focusses on software and internet technologies. The conception of the term Industry 4.0 is broader than in Germany and China. China has to catch up when it comes to automation in production. For them Industry 4.0 is closely connected to entire restructuring of manufacturing industry. The concept is based on Germany’s Industry 4.0 concept and puts an emphasis on smart manufacturing. The different starting positions of Germany, U.S.A and China influence the strategies and their focus areas. But since the overall strategic goals is the same, many similarities can be noticed.

7.2 Critical Acclaim

Industry 4.0 is a very present and complex topic. As it has been elaborated in this thesis, a precise definition does not exist. The world is more dynamic than ever before, and one is coming across new technologies on a daily basis. The fourth industrial revolution is a revolution that is not yet complete. Therefore, it is difficult to differentiate what is actually connected to Industry 4.0 and what are remnants of the third industrial revolution. It is a time of transition and each country is attempting to make the transition in a different way. Furthermore, the term is also used as a marketing tool for other purposes. To create a precise basis is challenging due to the sources given and the limitation in time and scope imposed by a bachelor thesis.

As the term has evolved in Germany, it is less difficult to analyze the strategy Germany is aiming at than U.S.A. and China. There are much more sources related to Industry 4.0 in Germany than in the other two countries. In Germany, there is a greater focus on Industry 4.0 than in the other countries. Moreover, strategies merge into each other in times of international cooperation, so they cannot easily be distinguished from each other. All three countries have developed strategies with a lot of key areas to focus on. It is not fully clear yet, which technologies will have the most important influence in the race for first place, therefore many are integrated. Concluding in the challenge to go into detail with every technology connected to the strategy. Additionally, the concepts created by the three countries do not yet provide a concrete action plan with solutions to the topic. They are rather proposals which still require a lot of trial and error. This indicates once again how complex the whole topic is. There are several influencing factors defining each interpretation and implementation of Industry 4.0. There is no right or wrong approach towards this new era. The strategies consist of recommendations for actions, research, discussions and guesswork. This is not surprising as Industry 4.0 is an ongoing process and develops with time. At the moment the initiatives are still in a phase where a lot of testing is being done. Only when the revolution is completed, an accurate analysis of interpretation and implementation of Industry 4.0 can be drawn.

7.3 Outlook

Industry 4.0 is a ubiquitous term and a topic with a lot of potential for discussion. The whole world is looking at the developments towards this new era. Therefore, it will also be a topic of future interest. Germany, U.S.A and China are diligently working on strategies to improve their situation and to achieve their overall goal.

The thesis only aims at analyzing the implementation and understanding of Industry 4.0. For the future it would be of great importance to analyze the influencing factors of development as well. The pace of development is influenced by expected and unexpected factors. Politics are an unexpected factor not to be ignored as it will have an even greater influence in the future. Trade wars, tariffs and trade relations can make the decisive difference in development. Though the fourth revolution is not only politics driven. Companies and their innovations already have a major influence in the development of Industry 4.0. In the future this influence may become even bigger. To be able to fully analyze Industry 4.0, all factors need to be taken into consideration. Furthermore, in order to see the impact of Industry 4.0 more reliable sources identifying the progress inside of companies need to be established. Though, this is already a difficult topic and might become even more difficult in the future. Outflow of knowledge, data protection and intellectual property are a few keywords related to that challenge. In a race for first place, each country wants and needs to protect their progress.

Moreover, it is not enough to come up with a strategy when it is not fully being implemented. For Germany it is important to start acting and stop discussing or it will be overtaken by others. In the upcoming years it will be exciting to observe the competition between these different industrial nations in the new field. No one can currently predict who will win it. But clear is, it could have serious consequences for the economy to oversleep the fourth revolution.

IV Glossary

5G	Upcoming fifth generation of wireless broadband technology. It will offer higher speed and better coverage than the current 4G (LTE).
Actuator	A device causing a machine or system to operate. It turns a signal into a mechanical action.
Additive Manufacturing	A comprehensive term for all manufacturing processes in which material is applied layer by layer to create three-dimensional objects.
Artificial Intelligence	Part of computer science that focusses on the creation of intelligent machines that have human features (e.g. speech recognition, learning, problem solving).
Augmented Reality	A computer-aided perception or representation that expands the real world by virtual aspects.
Big Data	Large amounts of data originating from e.g. the internet and saved, processed and evaluated using unique solutions.
Big Data Analytics	Examining large data sets to uncover e.g. information or unknown correlations to make business decisions.

Biotechnology	Technological applications that take usage of biological systems in order to to create products or technological systems.
Cloud Computing	Using a network server hosted on the internet to store, manage and process data, rather than a local server or personal computer.
Cyber-Attack	Deliberate exploitation of computer systems by using malware. Enabling cyber-crimes e.g. information theft or fraud.
Digitalization	Changing business models by integrating digital technologies into everyday life.
Encryption	Converting information or data into a code to prevent access which is unauthorized.
Fibre-Optic Connections	Used to transmit telephone signals, cable television signals and internet communication. Reaches high internet speed.
Machine Learning	A part of Artificial Intelligence describing dynamic algorithms which are able to learn independently to improve results and performance.

X

Mainframe Computer	Ultra high-performance computer that are made for high-volume, processor-intensive computing.
Value Added	Output of a sector after adding up outputs and subtracting intermediate inputs.
Neurotechnology	Technology that is concerned with the nervous system.
Programmable Logic Controller	An industrial digital computer used and adapted for the control of manufacturing processes.
Reference Architecture	Providing recommended structures and integrations of IT products embodying industry best practices.
Silicon Valley	Center of the American electronics and computer industry close to San Francisco.
Virtual Reality	The creation of a realistic simulation of a three-dimensional environment by using interactive software and hardware.
Web 2.0	Evolutionary step with regard to the offer and use of the World Wide Web. No fundamentally new technology, rather a socio-technical change.

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