Role of Startups in the Digital Transformation of the Steel Industry

Final Report

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ICT	Information and communications technology
IoT	Internet of things
IIoT	Industrial Internet of things
CPS	Cyber-physical system
CPPS	Cyber-physical production system
SAAS	Software as a service

1 Introduction

Industry 4.0 and digitalization are nowadays probably two of the most used buzzwords and only rarely defined in a clear and concise way. Before defining them more precisely for the purpose of this report in chapter 2.2, it can be said that they evolve around a fundamental change of industrial settings, driven by new kinds of information and communications technology (ICT). This will have a transformative effect on metallurgical value chains.

The question is which form this change and innovation will take on, given that the steel industry has its very own processes, unique value chain, (socio-) economic and business structure, and culture. Deriving from that, a highly relevant question is who will be the agents who drive this change and bring innovation to market. Will it be the steel companies themselves, the equipment providers, software companies or other market participants?

The essence of the research task is the question if and how startups can contribute to that change. In the end, a dominant question will be whether there is the chance for a mutually beneficial relationship.

1.1 Initial Situation and Problem Definition

Innovation has multiple interpretations. Most of them have in common that it involves a new form of an object, process or abstract concept, which has to be implemented and institutionalized in some way.[1] The change of industry mentioned above is based on creation of knowledge in fields such as computer science, applied mathematics, applied physics and other areas. However, this knowledge has to be brought to market, implemented and institutionalized in some form, i.e. being translated into an innovation. In fact, the difference between abstract knowledge and the corresponding innovation is a major source of business opportunities.

A fundamental hypothesis of the research endeavor is that startups are able to take advantage of these opportunities. In the field of industry 4.0 and the underlying ICT, it is essential to offer state-of-the-art products. Recent university graduates (as key employees of startups) are familiar with the newest form of knowledge and technologies in the enormously fast-paced ICT sector. Furthermore, startups can draw on multiple resources such as venture capital and subsidies and support by governments. Lastly, they can act very agile and are therefore able to adapt fast to new market situations.[2]

Industry 4.0 and the underlying massive changes in industrial value chains create a large range of new market opportunities. The steel industry is also not a typical target

[1] refer to Specht, D.; Möhrle, M. G., https://wirtschaftslexikon.gabler.de/definition/innovation-39624 (Retrieved: 19.05.2018)
[2] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 66 ff.

market for business-to-business startups and hence, a new company in that field might be confronted with less competition.

1.2 Objective and Research Question

The objective of the research is to understand startups' role in the field of industry 4.0, and specific to the steel industry. Out of this a number of research questions emerge. To answer them, the first step is to identify and understand the novel trends and technologies.

- What is industry 4.0 and what are the major new technological concepts in this field?
- What are their potential applications as well as current status and challenges of implementation?

Furthermore, it is important to understand the current status of industry 4.0 in the steel industry. As the length of the research project is limited this can only be done by looking at selected examples.

- What are examples of industry-4.0 technologies in the steel industry?

The second part explores the role of startups in corporate innovation in general.

- What is the role of startups in corporate technology and innovation management?

1.3 Research Methodology

Before a business opportunity can be established, the overall field of industry 4.0 has to be explained and defined. This is followed by a brief description of the related technologies and applications in the steel industry as well as an investigation into startup's role in corporate innovation. Finally, these topics are then discussed with experts in the steel industry and experts on industry-4.0 technology. It should be noted here that this is a shorter version of the author's master thesis, which was submitted to the University of Leoben as part of the author's master degree. The master thesis is the original and earlier version of this text and was adopted for this report.

2 Industry 4.0

The first part gives a foundation to formalize hypotheses and draft business models. Hence, it starts with an explanation of industry 4.0 and the inherent technological concepts. This is followed by briefly describing potential applications, current status and challenges of implementation as well as examples in the steel industry.

The term "industry 4.0" has a lot of different definitions and depending on the authorship of the specific literature, denotes different things. What all those definitions have in common is that they evolve around a process of change in industrial settings.

Of course, one can argue that industrial settings (and the world in general) are constantly changing due to the constant stream of new research findings and innovation. This raises the question, what is different or even more fundamental to the novelties around industry 4.0.

The inception of the term industry 4.0 or more precisely the German term “Industrie 4.0” is very often attributed to the “Hannover Messe” 2011, a trade fair for industrial technology.[4] It actually stands for a political initiative by the German government to establish Germany as a leading provider and market for advanced manufacturing solutions. The 4.0 comes from the idea that the new wave of technology will lead and be encompassed by the fourth industrial revolution.[5]

2.1 From Industry 1.0 to Industry 4.0

To put this into a historical context, the following paragraphs will describe the first three major technological revolutions. The first one, often dubbed industrialization in general, took place between the second half of the 18th and the first half of the 19th century. It was characterized by different technological trends, the most significant being the introduction of steam power. Also the use of water power became more efficient. This contributed to an emergence of mechanical production systems, which in turn led to a tremendous efficiency gain in the production of basic supplies, such as agricultural yield, food and clothes as well as to an increase in mobility and transport through steam-powered trains and boats. The technological novelties also had a fundamental impact on the structure of the economy and society in general: population boom, the emergence of capitalism, centralization of production in factories, impoverishment of industrial workers, urbanization and many more.[6]

The second industrial revolution, beginning around 1870 was driven by electrification, which allowed for decentralization as energy could be distributed across distances more easily. Another major impact had the introduction of production lines and conveyer belts as they facilitated a stronger division of labor, mass production and economies of scale, laying the foundation for today’s affluence. The combustion engine was introduced and industries such as petroleum, electrical, chemical and automotive as well as mechanical engineering gained in importance. A major societal change was the emergence of social-democratic and communist parties as well as trade unions among others.[7]

The third industrial revolution started in the 1960s and was mostly driven by the emergence of electronics and information technology, started by the introduction of the programmable logic controller. The following introduction of mechatronics and automation of industrial processes led to rationalization and efficient serial production. Broader trends were the transition from seller’s to buyer’s markets and beginning and

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[4] refer to Drath, R.; Horch, A. (2014), p. 1
[5] refer to Sharma, A.-M., https://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Industrie-4-0/Industrie-4-0/industrie-4-0-what-is-it.html?view=renderPrint (Retrieved: 13.05.2018)
[6] refer to Bauernhansl, T. (2014), p. 5 ff.
[7] refer to Bauernhansl, T. (2014), p. 5 ff.

now heavy customization. The internet accelerated globalization and facilitated global knowledge exchange and communication. Advanced transportation also contributed to a global division of labor and global market for most products, which in turn forced companies and market participants to specialize even further in order to succeed.[8]

Just as the previous ones the fourth industrial revolution is also driven by the emergence of new technology and organizational concepts. The introduction of the internet or internet-similar concepts into industrial processes opens up new possibilities and is thought to bring about a new way of how we produce goods and services. For example, physical objects can be represented in the digital space and real-time updates make it easier for operational managers to collect information and make decisions.[9] Cheaper sensors make it possible to collect a shire endless amount of data and increased computing power allows for more advanced data analytics to retrieve more meaningful and fundamental information. Computing power also allows for more advanced forms of artificial intelligence which leads to a new degree of autonomous processes, especially when combined with advanced robotics.[10] The four industrial revolutions are illustrated in Figure 2.

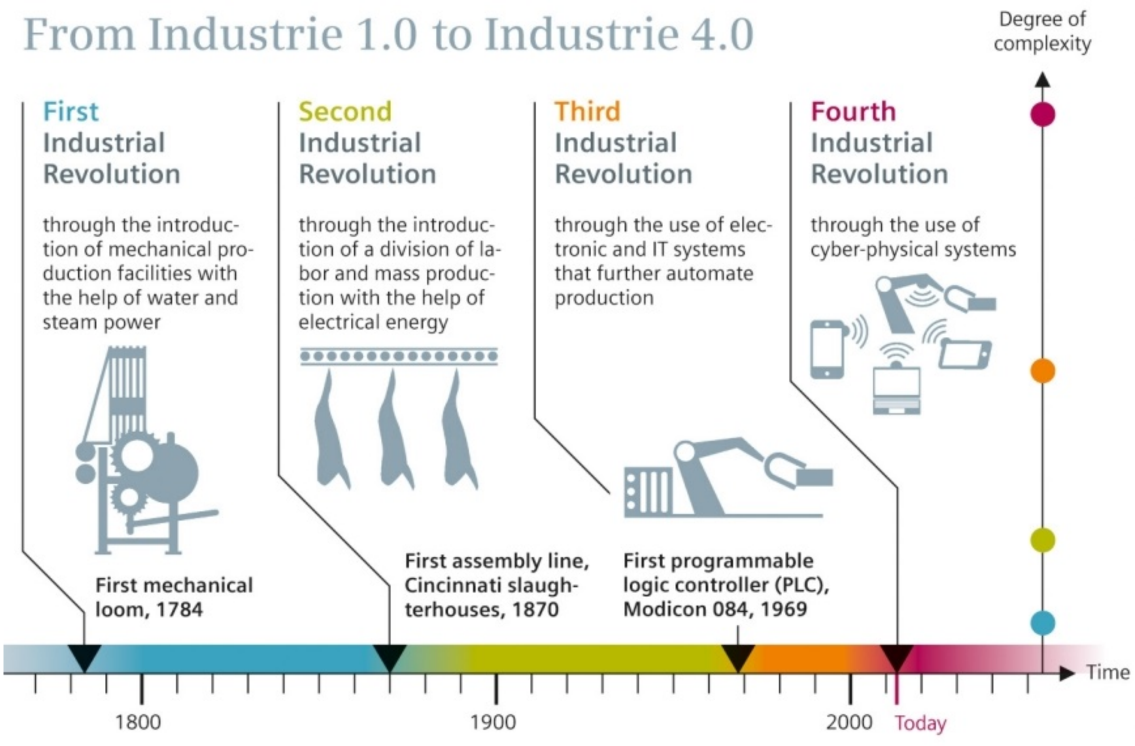

Figure 2: The Four Industrial Revolutions[11]

It is important to note that these technologies seem to incorporate a strong potential for change. However, this potential has yet to be realized and society is just at the beginning of this fourth industrial revolution. In fact, there is a tremendous marketing hype and "noise" around the term industry 4.0 and it remains to be seen whether

[8] refer to Bauernhansl, T. (2014), p. 5 ff.
[9] refer to Drath, R.; Horch, A. (2014), p. 2
[10] refer to Baur, C.; Wee, D., https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act (Retrieved: 13.05.2018)
[11] source: Eberl, U. et al. (2013), p. 20

industries can live up to the expectations. It is also not certain yet whether the changes will be seen as a major industrial revolution in retrospect.

2.2 Definition of the Term Industry 4.0

How can we define industry 4.0 when it encompasses such a broad wave of technologies? The German Federal Ministry for Economic Affairs and Energy defines it as follows (translated by the author): In the industrial context the term industry 4.0 means the connection of the digital world of the Internet with the conventional processes and services of the industrial sector. It is a horizontal and vertical interconnectedness along the value chain with a shift in management and control from top to bottom.[12]

In this definition industry 4.0 describes a state, not a process, which is characterized by connectivity and decentralized decision-making. The Association of German Engineers sees the Internet of things and services as the foundation for such a state, which is nothing more than the interconnection of physical objects (things) and services in an Internet-like infrastructure. Vertical interconnectedness means integration between the different firm levels such as strategic or operational management. Horizontal interconnectedness on the other hand denotes integration of elements and actors on the same firm level across factories and companies. The "Industry-4.0 House" illustrates this (Figure 3).[13]

Figure 3: Industry-4.0 House[14]

McKinsey & Company offers the following description: "We define Industry 4.0 as the next phase in the digitization of the manufacturing sector, driven by four disruptions: the astonishing rise in data volumes, computational power, and connectivity, especially

[12] refer to Bundesministerium für Wirtschaft und Energie (BMWi) (2015), p. 7
[13] refer to VDI Technologiezentrum (2014), p. 6
[14] source: VDI Technologiezentrum (2014), p. 7 edited by Chou, J., http://www.equipment-news.com/industry-4-0-needs-horizontal-integration/ (Retrieved: 19.05.2018)

new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing."[15]

Although this seems to describe a process, which it does to a certain extent, the essence of the definition seems to be industry 4.0 as the presence of certain technologies and features, which again can be explained as a state. The four categories are connectivity and data volumes, analytical capabilities, new human-machine interactions, and new technological concepts overall (such as 3D printers). This definition is expanding the previous one and encompasses a broader range of technologies.

Gabler Wirtschaftslexikon gives yet another definition (translated by the author): Industry 4.0 is a marketing term, which is also used in business communication and which stands for a future-oriented project of the German government. The so-called fourth industrial revolution, which the number refers to, is characterized by individualization (even in serial production), hybridization of products (pairing of products and services) and the integration of the customer and business partners in business and value-creation processes. Essential components are embedded systems as well as (partly) autonomous machines, which navigate through their surroundings and take decisions, and developments such as 3D printers. The interconnectedness of technology and items equipped with chips results in highly complex structures and cyber-physical systems as well as the Internet of things.[16]

Again integration across the value chain and the presence of certain technological concepts such as embedded systems, autonomous machines, 3D printing, cyber-physical systems and the Internet of things define industry 4.0 as a state. However, what is new is hybridization of products (pairing them with services) and individualization, enabled by the aforementioned technologies and leading to an even further increase in product and service variety.

As mentioned above, Industry 4.0 is actually a vision of a future state of industrial value chains and industrial settings. As such the term incorporates rational predictions about the potential of current technological novelties, emotions such as hopes and dreams as well as marketing messages. It is necessary to articulate a clear and concise definition though to understand what is meant by the term throughout the rest of the report, therefore the following working definition will be applied: *The term industry 4.0 is synonymous with a (future) state, which is characterized by connectivity, between the physical and virtual space in industrial settings, and between different horizontal and vertical levels of the industrial value chain. The term also means two categories of technologies and concepts in industrial value chains and industrial settings: first, those which enable this level of connectivity (e.g. sensors or the Internet) and second, those which have connectivity as a necessary condition (e.g. data analytics).*

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[15] Baur, C.; Wee, D., https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act (Retrieved: 13.05.2018)

[16] refer to Bendel, O., https://wirtschaftslexikon.gabler.de/definition/industrie-40-54032 (Retrieved: 14.05.2018)

Note that this definition cuts out the non-scientific "noise" such as marketing messages by equating the term industry 4.0 with the state it describes. The description of that state is centered on the concept of connectivity and on technologies, which enable and are enabled by connectivity. Also note that this definition involves a particularly wide range of technologies and concepts. All fundamental changes which transform the current industrial value chains into a state of industry 4.0 will be referred to as digitalization throughout the report.

2.3 Technological Concepts in Industry 4.0

The overall technological and scientific foundation of industry 4.0 involves multiple fields (computer science, communication technology, production science, mechatronics and ergonomics) as well as a wide range of specific theories such as data analytics, robotics and production technology (Figure 4). Some of the specific theories again contain a massive body of knowledge themselves (e.g. software engineering, artificial intelligence, materials engineering). As a result industry 4.0 is a highly heterogeneous and highly complex field and demarcation in scope and depth is needed. The chapter will therefore be limited to the two most central and fundamental concepts which are the industrial Internet of things and cyber-physical production systems.[17]

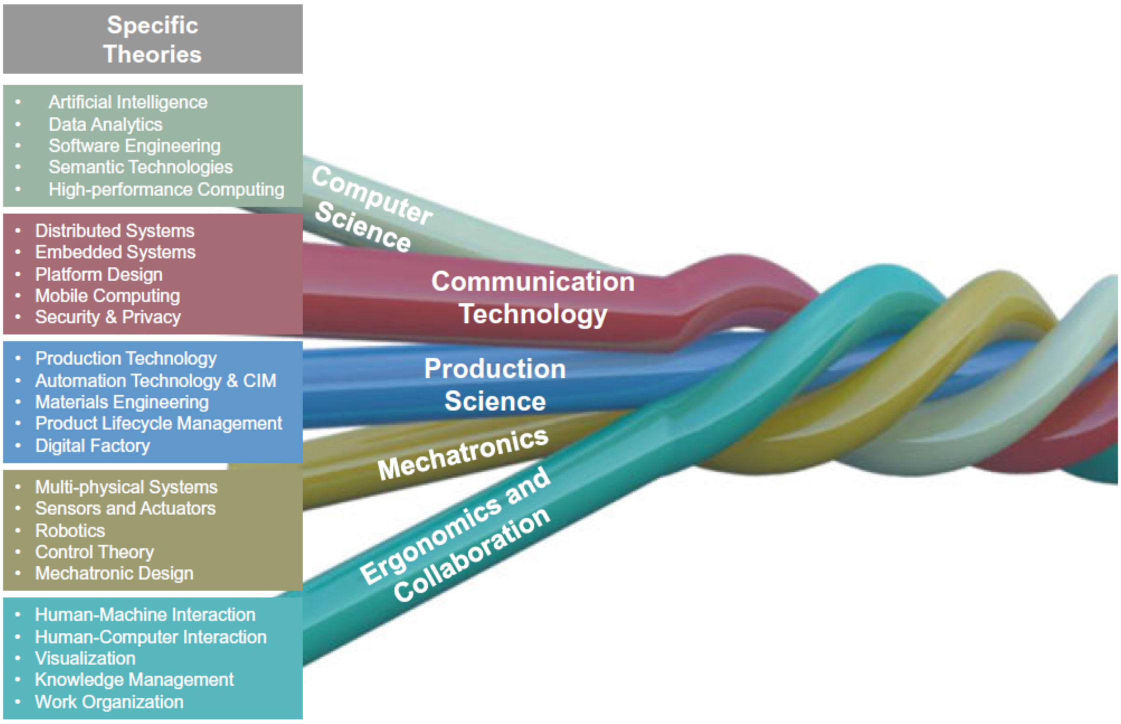

Figure 4: Technological and Scientific Foundation of Industry 4.0[18]

[17] refer to Jeschke, S. et al. (2016), p. 3 ff.
[18] source: Jeschke, S. et al. (2016), p. 7

2.3.1 Industrial Internet of Things

In order to understand the industrial Internet of things (IIoT) it is necessary to define and understand the Internet of things (IoT). Usually, when we refer to “the Internet” we refer to the Internet of computers, i.e. a global system of computer networks which communicate via a standardized system of rules.[19] In case of the Internet of computers this standard communication protocol is the Internet protocol suite, also known as TCP/IP, named after two foundational protocols (Transmission Control Protocol and Internet Protocol). The IoT extends the concept of the Internet to objects which have previously not been part of an Internet-like infrastructure.[20] Postal service (and logistics in general) provides examples where IoT has been introduced successfully: a sent package can be tracked based on a bar code and a bar code reader which is connected to an Internet-like infrastructure. This provides real-time information and transparency on the location of the package.

The IoT is a complex system of systems, which integrates different theoretical fields and applied sciences (similar to industry 4.0 in Figure 4). Explanations of IoT are often fuzzy and dependent on the “subfield lens” it is observed from. The RFID Working Group of the European Technology Platform on Smart Systems Integration provides a very concise definition by describing it as “a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols”.[21] Just as the Internet of computers allows computer networks to “interact” by providing rules on communication and the supporting infrastructure, the IoT provides the same for physical objects. The industrial Internet of things (IIoT) on the other hand is the same concept applied (and limited) to industrial settings. The production items, machines, equipment, sensors, actuators and other objects can be addressed and can be linked to a virtual representation (digital twin) containing additional information on identity, status or location. They can also send and receive information and provide services based on this information.[22] As in other IoT applications this opens up a multitude of possibilities such as data collection and analysis, extended and automated documentation, automated adjustments of process parameters and many more.[23]

Figure 5 shows the general architecture of an IoT system which spans from the human on the one end to the physical objects and shop floor processes (if applied to industrial settings) on the other end. The spectrum starts with the perception layer which consists of physical items such as sensors, actuators, machines or production items. Data (e.g. temperature or chemical composition) is measured by sensors, actuators act upon the physical processes and production items are located, based on different enabling technologies such as RFID or infrared.[24] The underlying technologies span across multiple scientific fields and depend among other things on the process environment.

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[19] refer to INFSO D.4 Networked Enterprise & RFID INFSO G.2 Micro & Nanosystems; RFID Working Group of the European Technology Platform on Smart Systems Integration (2008), p. 6
[20] refer to Khan, R. et al. (2012), p. 1 ff.
[21] INFSO D.4 Networked Enterprise & RFID INFSO G.2 Micro & Nanosystems; RFID Working Group of the European Technology Platform on Smart Systems Integration (2008), p. 6
[22] refer to Gubbi, J. et al. (2013), p. 2
[23] refer to Schöning, H.; Dorchain, M. (2014), p. 543 ff.
[24] refer to Khan, R. et al. (2012), p. 2 ff.

The perception layer exchanges information with the network layer which transfers it to the information processing system. The transmission can be wired or wireless with enabling technologies such as 3G, Wifi or Bluetooth. The adjacent middleware layer is responsible for service management and makes sure that the different systems work together. The devices in the perception layer provide different kinds of services (such as collecting temperature data in a specific spatial area). The middleware makes sure that each device only interacts with devices which implement the same service type. It also provides storage and performs computation and information processing in order to take autonomous decisions depending on the results.[25] The idea of the middleware is to provide resources which are used by different systems in an isolated manner so that they do not have to be duplicated in each system.[26] Finally, the application layer enables humans to manage the different functionalities and supports user applications such as access to database or visualization of important information. The business layer allows for system management and provides information in the most aggregate form, in order to determine future action and business strategies.[27]

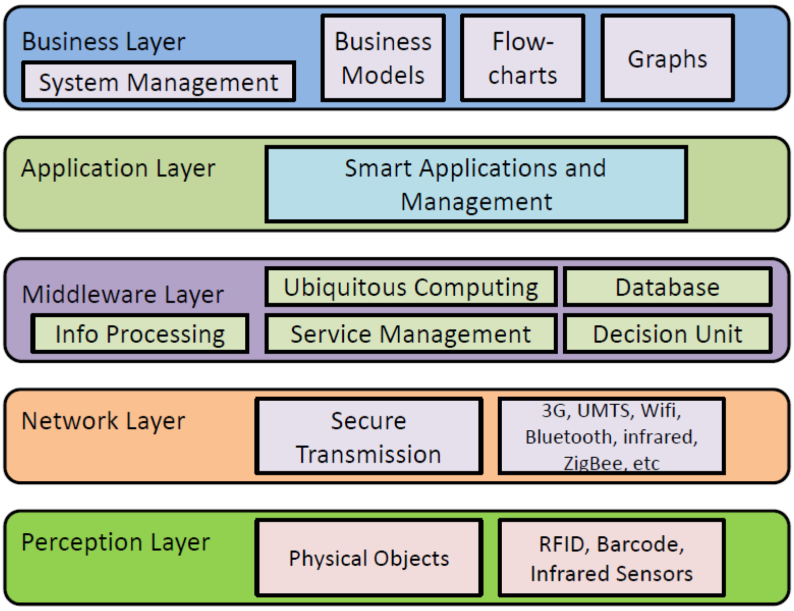

Figure 5: IoT Architecture[28]

The IIoT is an integral and fundamental part of industry 4.0 as it is foundational to its level of connectivity and the technologies and services which build on it. Some authors even use IIoT as a translation for the German “Industrie 4.0”.[29] However, it is important to note that just like industry 4.0, IIoT is still mostly a vision and implemented only to a small extent. Furthermore, it has challenges to overcome such as interoperability between devices, data confidentiality or network stability (chapter 2.4 gives a detailed account of the challenges of industry 4.0 in general).[30] Nevertheless, it allows for the

[25] refer to Khan, R. et al. (2012), p. 2 ff.
[26] refer to Gubbi, J. et al. (2013), p. 6
[27] refer to Khan, R. et al. (2012), p. 3
[28] source: Khan, R. et al. (2012), p. 3
[29] refer to Jeschke, S. et al. (2016), p. 3
[30] refer to Khan, R. et al. (2012), p. 4

integration of revolutionary technologies such as artificial intelligence or advanced robotics into industrial value chains. Hence, the technological potential of an IIoT infrastructure might be tremendous.

2.3.2 Cyber-Physical Production Systems

In the last decades technological progress in different fields increased the complexity of overall system of systems such as cars or airplanes. They increasingly became a network of different embedded systems, i.e. a network of different combinations of hardware and software components.[31] The ever increasing capabilities of the different sub-systems made coordination between them a necessity to share and allocate the specific functions. The emergence of these networked embedded systems went hand in hand with the emergence of wireless sensor networks.[32] The latter is a network of a large number of sensors communicating via wireless technology. The emergence of these was driven by technological advances in integrated circuits (resulting in low-cost, low-power miniature sensor devices) and in wireless communication.[33] All of this led to the confluence of the virtual software systems with the physical components, including sensors and actuators, and the emergence of cyber-physical systems (CPS).

The Cyber-Physical European Roadmap & Strategy, a project co-funded by the European Union, defines a CPS as consisting of “computation, communication and control components tightly combined with physical processes of different nature, e.g., mechanical, electrical, and chemical”.[34] It consists of physical elements (and processes) such as machines or energy sources; cyber, i.e. virtual, elements such as software or computation; and cyber-physical interfaces such as sensors (physical-to-cyber connector) or actuators (cyber-to-physical connector).[35]

A CPS can also be explained by introducing three hypotheses: First, communication infrastructure in industrial processes or elsewhere will become cheaper and, therefore, be introduced everywhere. Second, all physical elements such as plants and factories will be connected to an Internet-like structure and are available as data objects. Hence, they become “searchable, explorable, and analyzable”.[36] Third, the mentioned elements will be able to store documents and knowledge about themselves in the network. This virtual presence is always up-to-date and may include data such as simulation models or simple requirements. On top of that there is a second layer of functionality such as negotiation or exploration functions which act on behalf of the objects. In conclusion, there are three levels to a CPS: the physical object, the data model of the object in a network infrastructure (including relevant information) and services based on this model (Figure 6).[37]

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[31] refer to Promotorengruppe Kommunikation der Forschungsunion Wirtschaft – Wissenschaft (2013), p. 85
[32] refer to CyPhERS – Cyber-Physical European Roadmap & Strategy (2013), p. 9 ff.
[33] refer to Gubbi, J. et al. (2013), p. 5
[34] CyPhERS – Cyber-Physical European Roadmap & Strategy (2013), p. 8
[35] refer to Rajhans, A. et al. (2009), p. 3 ff.
[36] Drath, R.; Horch, A. (2014), p. 2
[37] refer to Drath, R.; Horch, A. (2014), p. 1 ff.

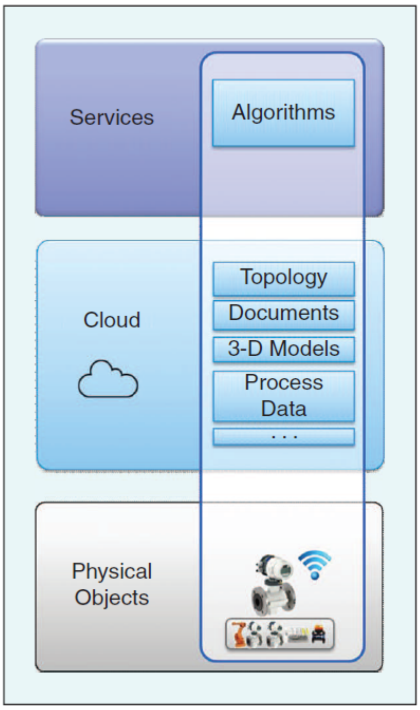

Figure 6: Model of a Cyber-Physical System[38]

This allows for a distinction between the IoT and a CPS. The latter builds on the concept of IoT but is not the same, especially with regard to the service component. The IoT is a network of objects, which enables but does not include these services. However, they are an integral part of a CPS. The IoT is associated with a network idea (an extension of the Internet of computers) while the concept of a CPS evolved out of the necessity to integrate and coordinate the growing capabilities and functions of sub-systems in an overarching system.[39]

A cyber-physical production system (CPPS) is a cyber-physical system applied (and limited) to industrial value chains and industrial settings. CPPSs are integral to industry 4.0 as they build services and technologies on top of the connectivity implemented by the IIoT. According to the working definition of industry 4.0 in chapter 2.2 these services are a foundational part of the state called industry 4.0. To give an example, a CPPS enables a constant and autonomous supervision of the production processes. It can also implement negotiation functions between the different elements in the industrial value chains (based on the unique identities assigned by the IIoT). These functions may be able to use and evaluate a larger volume of data in order to achieve more accurate decisions in case of a conflict of objectives.

It also allows for a stronger integration of cloud computing in a firms ICT infrastructure. Cloud computing is an on-demand and self-service concept to access different computing resources such as storage capacity or servers. It enables broad network accessibility (with different devices), rapid elasticity (to scale with demand) and measured services (to monitor resource usage).[40] This brings a multitude of

[38] source: Drath, R.; Horch, A. (2014), p. 2
[39] refer to Jeschke, S. et al. (2016), p. 7 f.
[40] refer to National Institute of Standards and Technology (2011), p. 6 f.

advantages, one of which is scalable (i.e. flexible) computing capacity: legacy controlling and planning architectures often have the problem of fixed (i.e. static) computing power. This means that it can process normal day-to-day tasks, but is overwhelmed once a more complex problem or simulation (such as short-term order changes) has to be carried out. A cloud-based architecture is better equipped to draw on additional computing capacity and scale it (or shrink it) to the necessary performance.[41] Cloud services can also alleviate the burden on mobile devices such as tablets or personal digital assistants. Transferring computing or storage tasks to the cloud can lead to longer battery life or faster execution.[42] Just with the IIoT, CPPSs are still mostly a vision though and only implemented to a small extent. They are confronted with similar challenges as the IIoT and industry 4.0 in general (chapter 2.3.1 and chapter 2.4). However, they also incorporate a tremendous potential which will be included and dealt with in the next chapter.

2.4 **Potential Applications, Current Status and Challenges of Industry 4.0**

There is a large variety in potential applications in the field of industry 4.0. Figure 7 shows a range of these application fields organized in eight value driver categories, which are service and aftersales, resource and process, asset utilization, labor, inventories, supply and demand match, quality, and time to market. These categories show where industry-4.0 technologies can make a valuable contribution. Remote maintenance would be an example in the service and aftersales value driver category: In case of CNC machining for example, it is possible to monitor the operation status and machine condition remotely. In case of strong deviations, the machine manufacturer can provide maintenance service directly without any contribution from the CNC machining company.[43]

It is important to note that this is not a comprehensive list nor is it possible to compose a comprehensive list as the field is highly heterogeneous as well as still emerging and rapidly changing. In the coming years there will be new applications substituting current ones and the complexity and breadth of the field makes it next to impossible to list all applications. In fact, the implementation of industry-4.0 technologies is heavily dependent on the particular industry. For example in the automotive industry it has different characteristics than in the chemical or mining industry. Especially the differentiation between discrete production systems (such as the automotive industry) and process industries (such as the chemical industry) is important. Nevertheless, it is important to have a global overview of the most common applications. Implementations specific to the steel industry are described in chapter 3.

[41] refer to Verl, A.; Lechler, A. (2014), p. 235 ff.
[42] refer to Tang, C. et al. (2018), p. 1 f.
[43] refer to Mori, M.; Fujishima, M. (2013), p. 11 f.

Figure 7: Application Fields of Industry 4.0[44]

[1] machine repair and operation

The potential of industry 4.0 has numerous different aspects depending on the scientific and professional perspective. For example, an economic policy advisor has a different view on the subject than a computer scientist. For the purpose of the research it is particularly important to understand the perspective of industry managers. A survey across different industries, different company sizes and different seniority levels of respondents in Germany yielded the estimate shown in Figure 8. The new technologies are expected to have the biggest impact ("degree of the effect") on planning and controlling as well as customer satisfaction and greater flexibility. Time to market, quality and individualization of products are also expected to be improved.[45]

[44] source: Baur, C.; Wee, D., https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act (Retrieved: 13.05.2018) (slightly modified)

[45] refer to PricewaterhouseCoopers (2014), p. 22 f.

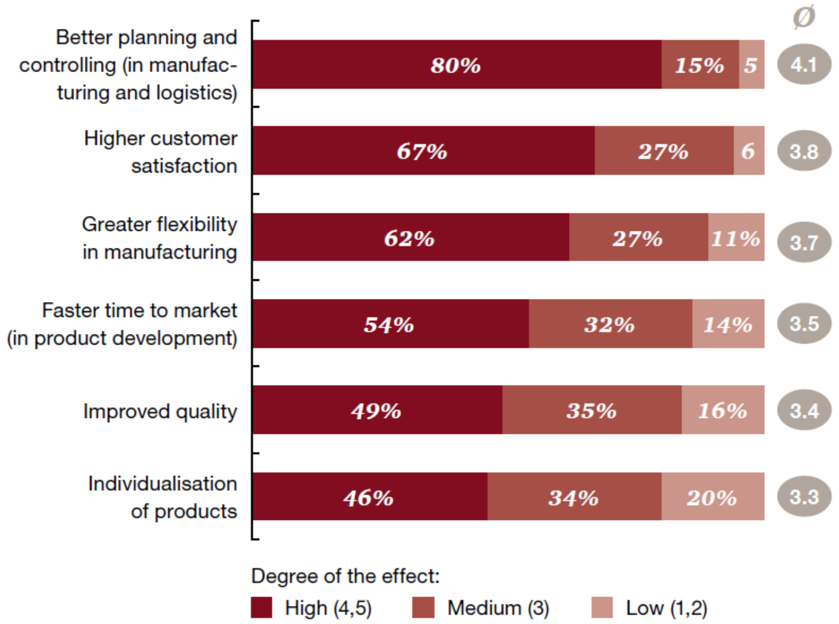

Figure 8: Expected Impact of Industry 4.0[46]

A survey concerning implementation across multiple industries and different company sizes in the US, Germany, China and Japan showed that digital quality and performance management, statistical process control, remote monitoring and control as well as real-time yield optimization have the highest degree of implementation. This is true for relevant use cases (applications in the planning, pilot or rollout stage) as well as company-wide rollouts (Figure 9).[47] It is not surprising that the percentage of company-wide rollouts (between a quarter and a third) is smaller than the percentage of use cases (around three quarters).

[46] source: PricewaterhouseCoopers (2014), p. 23
[47] refer to: Behrendt, A. et al., https://www.mckinsey.com/business-functions/operations/our-insights/how-to-achieve-and-sustain-the-impact-of-digital-manufacturing-at-scale (Retrieved: 28.05.2018)

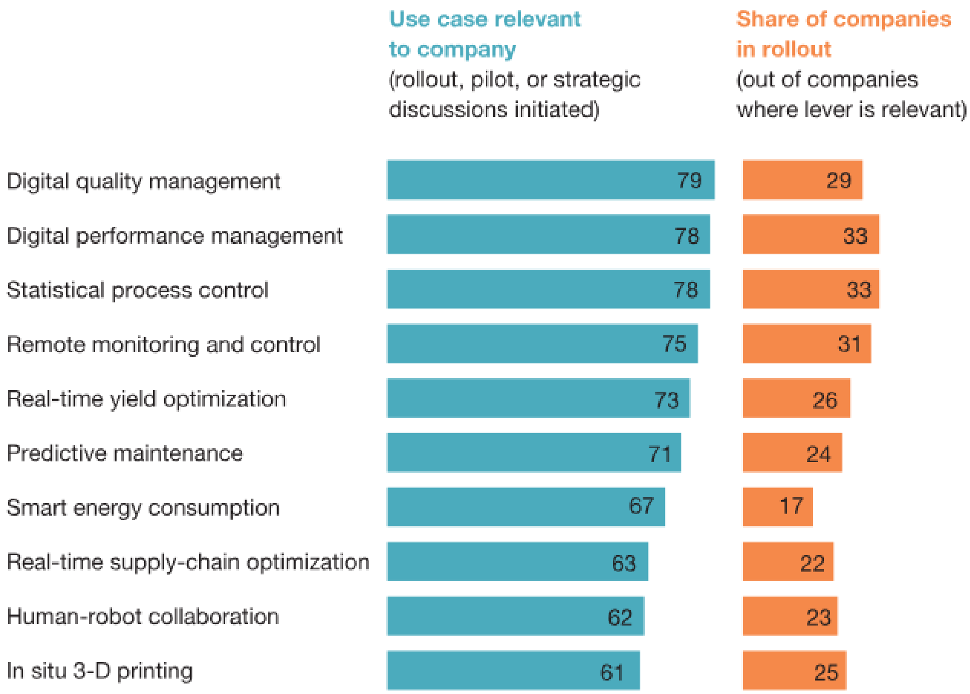

Figure 9: Current Status of Implementation[48]

numbers in percent of surveyed companies

The key challenges in the industrial (and business) context are of technological and organizational nature. The former start with assigning unique (technical) identities to the individual objects in the IIoT infrastructure. As the IIoT will potentially connect a tremendous amount of elements, a systematic approach is needed in addressing them. Furthermore, sensors and other devices may have to be changed frequently and the system must be able to dynamically adapt. The large amount of elements also comes with a large variety in devices, manufacturers and services. Standardization and interoperability is therefore necessary to make sure that the system works close to seamlessly. Another challenge is the limitation in wireless communication spectrum in light of the data volume which is to be transmitted. The capacity of dedicated spectrum is a finite resource and hence a dynamic spectrum allocation mechanism has to be established. Finally, security and safety are an enormous challenge, especially in the field of information privacy, data confidentiality and integrity, intruder's access to physical objects as well as network and infrastructure stability.[49] Still other challenges include power supply of elements which are attached to moving objects, energy efficiency of current wireless technologies, software complexity and system robustness in a dynamic technical environment.[50]

Organizational challenges include insufficient qualifications of employees and attracting as well as retaining appropriately trained specialists. As shown in chapter 2.3, industry 4.0 is a highly multidisciplinary field which creates demand for new skills such

[48] source: Behrendt, A. et al., https://www.mckinsey.com/business-functions/operations/our-insights/how-to-achieve-and-sustain-the-impact-of-digital-manufacturing-at-scale (Retrieved: 28.05.2018)
[49] refer to Khan, R. et al. (2012), p. 5
[50] refer to Mattern, F.; Floerkemeier, C. (2010), p. 249 ff.

as machine learning or robotics. As these skills have previously not been needed, personnel and recruitment strategies and tactics may need to adapt which takes time and effort. Furthermore, the technological advances and the potentially large impact on industrial value chains create the need for formulating an overall industry-4.0 strategy to cope with the changes and unlock the inherent advantages. However, the complexity of the topic is a challenge. Also procurement of technology and services needs to be adapted while initially there might be a lack of knowledge about the appropriate partners. Finally, missing clarity on return on investment and concerns about data issues (management, security, integrity etc.) are major obstacles.[51] Still other challenges are (perceived) excessive investment amounts, slow expansion of basic technologies such as broadband and missing legal clarity in different aspects of the new technologies.[52]

3 Industry 4.0 Applications in the Steel Industry

The aim of this chapter is to give an overview of steel production and the industry and show the practical implications of the technological concepts described above. It is important to understand that the illustrations of industry-4.0 applications are not comprehensive nor is it possible to compose a comprehensive list of all implemented applications due to the size and diversity of the global steel industry. Rather it should exemplify the current state of industry-4.0 technologies in the steel industry. For this reason, automatic surface defect inspection and tracking during flat steel production, a big data solution for quality improvement as well as automatic reallocation of non-conforming products are explained in the following subchapters.

3.1 Basics of Steel Production

Steel is an iron-based alloy with less than 2 % carbon (certain steel grades contain more than 2 %, in particular chromium steel grades) and other alloying elements. Steel grades can be categorized into unalloyed steels (mass fractions of individual alloying elements do not surpass a certain threshold), stainless steels (at least 10.5 % chromium and a maximum of 1.2 % carbon) and other alloyed steels. Cast iron is an iron-based alloy with carbon content between 2 and 4 % which is not subject to any forming processes after casting.[53]

The processes to produce cast steel can be divided into iron making, steel making, secondary metallurgy and casting while there are four individual process routes (Figure 10). About 71 % of production is handled via the blast furnace route.[54] Iron ore is pre-processed (to get rid of impurities), agglomerated to sinter or pellets (if necessary) and charged into the blast furnace, together with coke and other carbon carriers as well as

[51] refer to McKinsey & Company (2017), p. 10
[52] refer to PricewaterhouseCoopers (2014), p. 36
[53] refer to Schenk, J. (2012), p. 2–3 ff.
[54] refer to Schenk, J. (2015), p. 14 f.

fluxes. Throughout the process carbon reduces the oxygen content while reactions in the lower part of the furnace cause the input to melt. The product of the blast furnace (hot metal or pig iron) is charged into the basic oxygen converter, together with scrap, and blowing of oxygen reduces the carbon content, which yields crude steel.[55]

Another 23 % of crude steel is produced via the electric arc furnace route, which roughly speaking remelts steel scrap with electric energy, together with other iron carriers, alloying elements and fluxes.[56] Direct reduction (5 % of global crude steel production) uses natural gas to reduce the oxygen content in iron ore. The solid product (sponge iron) is charged into the electric arc furnace. Finally, less than 1 % of global production is handled via melting reduction, which also produces hot metal to be charged into the basic oxygen converter.[57]

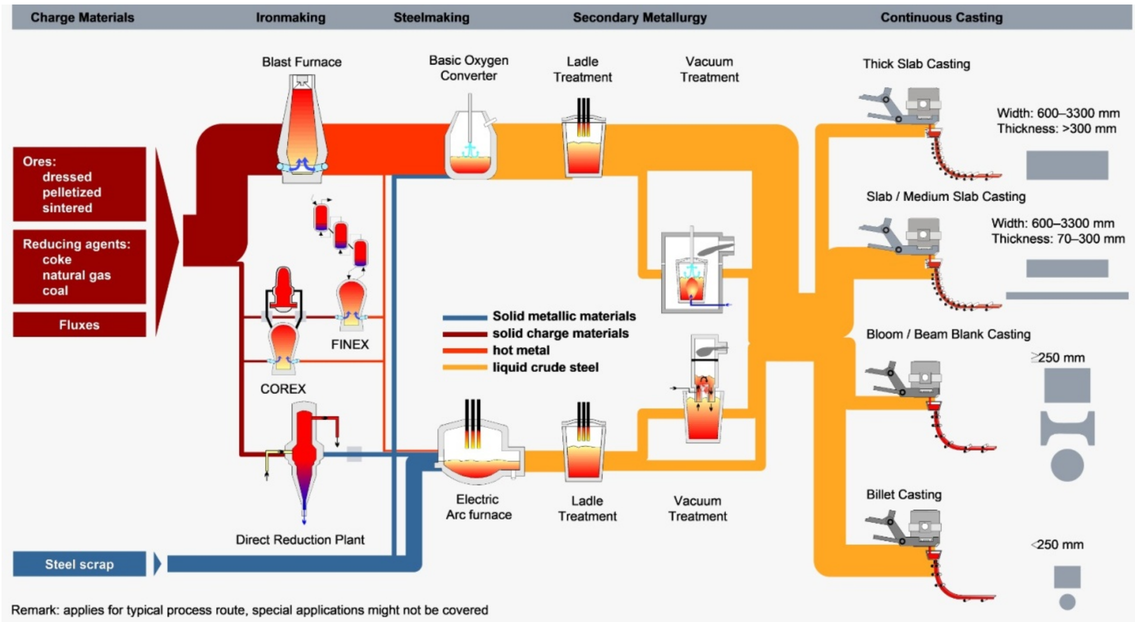

Figure 10: Process Flow Chart for Steel Production[58]

The crude steel still contains impurities and does not have the final chemical composition. Therefore, secondary metallurgical processes such as ladle treatment (to adjust temperature and add alloys for example) and other operations are necessary to achieve the right quality. The steel is then cast into slabs, blooms or billets, mostly using a continuous casting process.[59] Afterwards it is formed (using either rolling or forging technologies), undergoes heat treatment (to adjust material properties) and surface treatment (such as galvanizing to apply a protective zinc layer) as well as further processing (such as pipe welding, drawing or grinding).[60]

55 refer to Schenk, J. (2012), p. 3–5 ff.
56 refer to Schenk, J. (2015), p. 14 f.
57 refer to Schenk, J. (2015), p. 14 ff.
58 source: Siemens VAI, used by Schenk, J.; Bernhard, C. (2013), p. 2–12
59 refer to Schenk, J. (2012), p. 3–6
60 refer to Schenk, J. (2012), p. 3–4

3.2 An Overview of the Steel Industry

With approximately 1.7 billion tones of global crude steel production per year, steel is by far the most important engineering and construction material. Reasons are the availability of iron ore (5 % of the earth's crust), the economic production of the material and a massive variety of steel grades and associated properties, which caters to nearly every engineering need. The latter comes from the fact that it can be alloyed with a large number of elements and heat treatment is another lever to adjust material properties.[61]

Nearly 50 % of crude steel is produced in China while Asia in total has nearly 70 % (Figure 11). The ten largest steel companies (by tonnage) are ArcelorMittal, China Baowu Group, NSSMC Group, HBIS Group, Posco, Shagang Group, Ansteel, JFE Steel, Shougang Group and Tata Steel Group.[62] The global turnover of the industry is around $ 900 billion.[63] The industry is currently subject to several megatrends: globalization and increased international competition, the growth of China, overcapacity, digitalization, environmental concerns and legislation (the industry is one of the largest emitter of green house gases) as well as technological disruption in important customer segments (such as electrification of the automotive industry).[64]

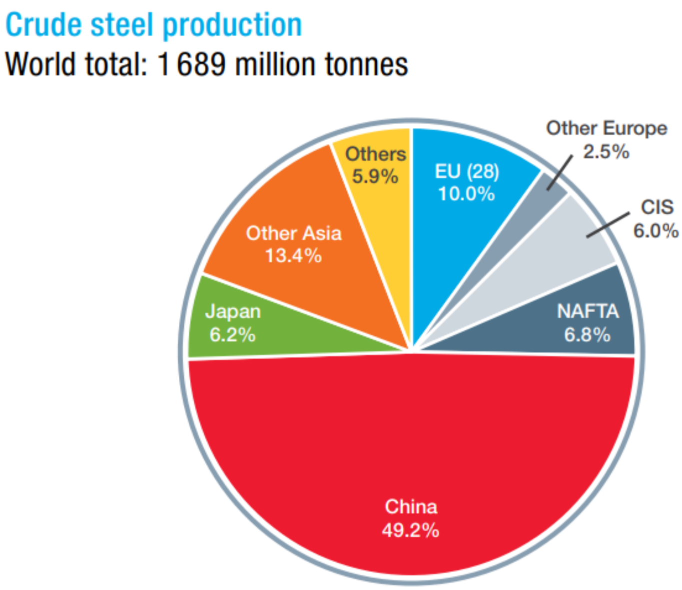

Figure 11: World Crude Steel Production[65]

The large variety of products and steel grades makes not only the individual process chains but also the strategies of the individual firms highly heterogeneous. The (business) strategy in this case can be seen as a pattern in the collectivity of decisions,

[61] refer to Schenk, J. (2012), p. 2–3
[62] refer to World Steel Association (2018), p. 9
[63] refer to Bălan, G. et al. (2016), p. 511
[64] refer to Bălan, G. et al. (2016), p. 511 ff.
[65] source: World Steel Association (2018), p. 15

which guides strategic management in their effort to align internal capabilities and subsystems of the company with external factors and circumstances.[66]

A fundamental aspect of this pattern is the positioning in the quality pyramid, which can be used to categorize the firms. The quality pyramid is a concept to illustrate the strategic landscape of the industry. Moving from bottom to top of the pyramid, the quality requirements (for example demanded steel cleanness) as well as the unit price increase (in part tremendously) and aggregated volume output decreases. Depending on where a steel company is positioned in this pyramid, different strategic aspects are important.[67] On top of the pyramid, steel products are highly differentiated and quality aspects of products and related processes are of high strategic relevance. On the lower end of the pyramid, the related steel has characteristics of a commodity with a low degree of differentiation. The production processes are easier to imitate and the (technological) barrier to entry is lower. Process efficiency, economies of scale and cost leadership are more central. Technology and innovation still play a vital role though since they can be leveraged to achieve these goals, for example through a higher degree of automation. Aspects such as those in connection with establishing lean processes and decreasing unit cost are important.[68]

The positioning in the quality pyramid also influences the structure of the value chain as a whole (Figure 12). For example, high-quality steel producers need different equipment (such as electric slag remelting equipment) and have more rigorous requirements regarding raw materials. An initial hypothesis going into the research is that industry-4.0 technologies will change the process chain as well as the value chain of steel production.

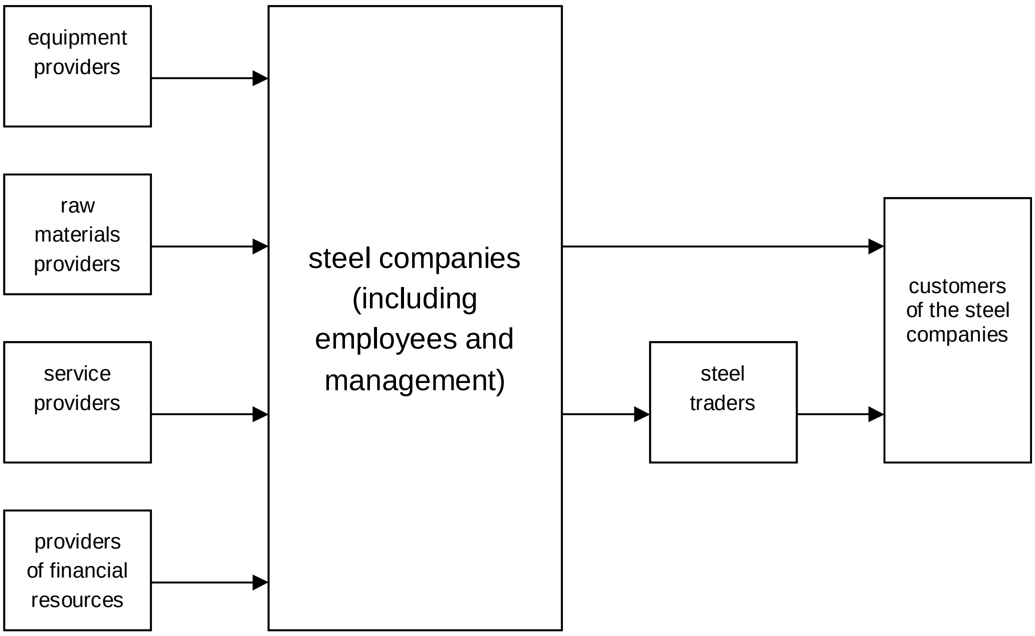

Figure 12: Simplified Value Chain in the Steel Industry

[66] refer to Phaal, R. et al. (2004), p. 8 ff. Feldmann, C. (2007), p. 64 ff.
[67] refer to Feldmann, C. (2007), p. 88 f.
[68] refer to Feldmann, C. (2007), p. 88 ff.

3.3 Examples of Industry 4.0 Applications

The following chapters are intended to illustrate applications of the new technologies in steel production as well as the inherent advantages. The first two examples are related to quality control and improvement of the steel product while the third example shows advancements in planning and production scheduling.

3.3.1 Automatic Defect Inspection and Tracking on Flat Steel

Surface defects such as slivers, blisters or scratches on steel strip products cause serious disturbances in the car manufacturing process which is one of the largest application fields for flat steel products. Surface defects cannot fully be avoided, repaired or eliminated during the production of steel strip. Therefore it is necessary to know about the occurrence and the location of them and to pass on this information to the automotive manufacturer so they can take appropriate action.[69] The first step to achieve this is to detect and classify them by using automatic optical inspection. The concept is shown in Figure 13 and builds among others on light sources, cameras and a fast image processor. If the velocity sensor detects that a strip is approaching the measuring unit, the microcontroller (MCU) switches on light sources such as LED, which provide adequate and near to uniform illumination. The reflected light of the steel surface is captured by the imaging sensors of the cameras and the signals are transferred to an image processing unit via fiber adapters. There defects are localized and classified according to a number of features extracted from the pertaining region. Each class has a specific combination of features and the classification is based on adaptive (machine) learning, i.e. algorithms which improve their performance with increasing data amount.[70]

[69] refer to Dunand, M. et al. (2014), p. 35 f.
[70] refer to Neogi, N. et al. (2014), p. 4 ff. Luo, Q.; He, Y. (2016), p. 16 ff.

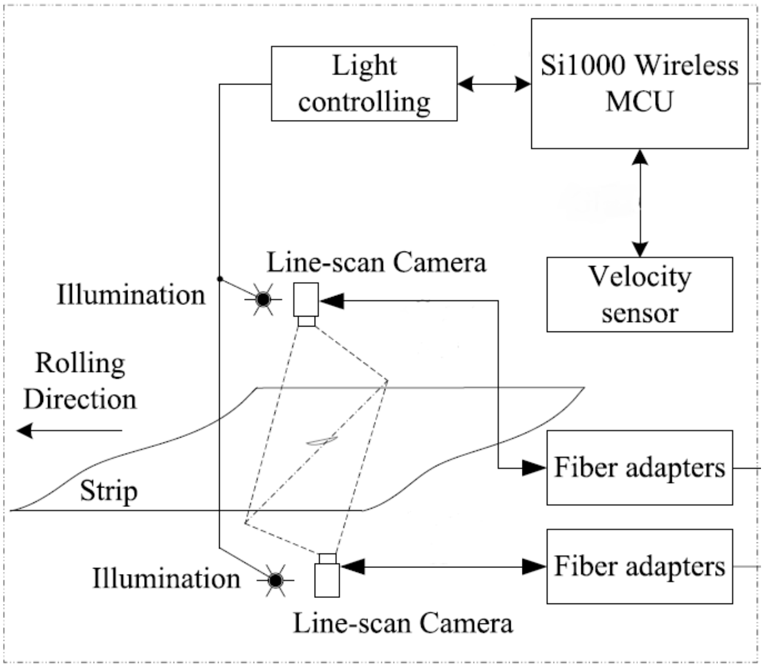

Figure 13: Concept of Automatic Optical Inspection[71]

The automatic optical inspection generates the information which surface defects occurred and where they are located. However, due to the fact that the strip is cut into shorter pieces, it is necessary to uniquely identify each meter of strip and attach the applicable information about surface defects. This is done by printing barcodes on each section of strip and matching the quality information with the individual barcode on a data file. After receiving the flat steel, the car manufacturer can retrieve this information and match it to the applicable strip section by using a barcode reading unit. This increases press shop yield and transparency about strip quality, decreases the need for inspection and handling parts after pressing and overall contributes to a higher efficiency and process stability.[72]

3.3.2 Big Data Solution for Quality Improvement on Flat Steel

At ILVA s.p.a., an Italian steel producer, a cause-and-effect analysis was carried out to understand the occurrence of ripple defects during the hot-dip galvanizing process. Occurrence and gravity of ripples, a surface defect, are affected by a number of process parameters such as process speed, air blade configuration or cooling procedures. Although it is possible to cope with this kind of defect by deploying nitrogen as a wiping medium, the specific (causal) effect of each parameter was not clear. A deeper understanding of the causal connection is desirable to achieve a better surface quality and save on (expensive) nitrogen.[73]

Modern measuring systems gather large amounts of high-resolution quality and process data. These are aggregated on length segments of the flat steel and stored in a company-wide quality database. However, to explore causal relationships the

[71] source: Luo, Q.; He, Y. (2016), p. 18 (slightly modified)
[72] refer to Dunand, M. et al. (2014), p. 35 ff.
[73] refer to Brandenburger, J. et al. (2016), p. 55 ff.

absolute coil position is only of minor importance and a more statistical view on the data is necessary. Furthermore, if a defect is caused further upstream in the process, it is necessary to add data of preceding process steps, which may not be possible using classic data models. The data model, which was used for the stated problem, assumes the flat steel as a constant grid and each disjoint grid cell as a rectangle. Aggregation of the available data over the rectangle (also called tiles) yields a corresponding value of the measured parameter. By assigning unique identification to each tile it is further possible to aggregate grid data over multiple coils.[74]

Furthermore, to ensure user acceptance it is necessary for the system to react fast to user commands. Due to the fact that a high-resolution grid takes longer to be displayed, the data is stored in different resolutions simultaneously (multi-scale data model). If data is requested, the grid displays something immediately (the coarsest resolution) while the full resolution is calculated. Figure 14 shows both principles combined, a multi-scale grid representation, from coarsest resolution (stage 0) to highest resolution (stage 8).[75]

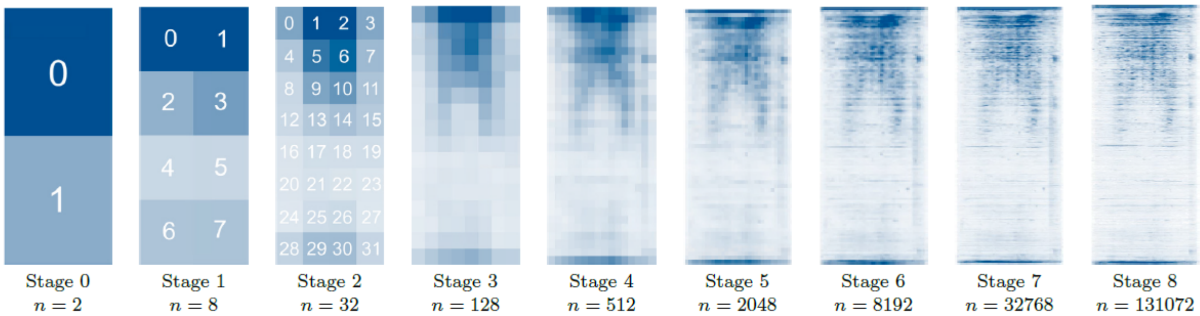

Figure 14: Multi-scale Grid Representation[76]

A classic three-tier architecture (Figure 15) provides access to the data. A database management system at the bottom implements the high-resolution data model and communicates with the Web Map Tile Server via SQL, a programming language. The Tile Server performs calculation on data, handles communication and processes commands depending on requests from the browser application, which includes the human-machine interface.[77]

[74] refer to Brandenburger, J. et al. (2016), p. 55 ff.
[75] refer to Brandenburger, J. et al. (2016), p. 55 ff.
[76] source: Brandenburger, J. et al. (2016), p. 56
[77] refer to Brandenburger, J. et al. (2016), p. 57

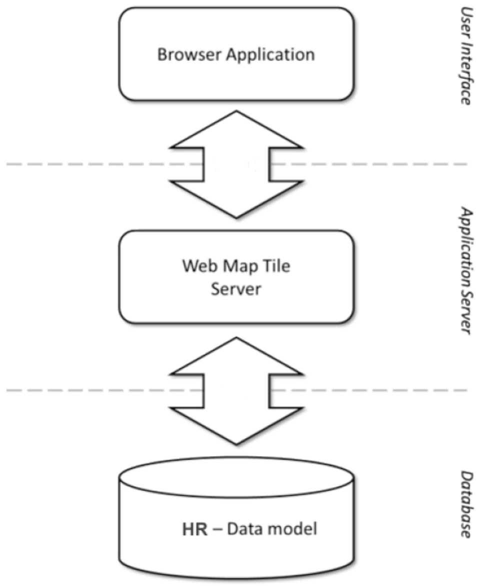

Figure 15: Three-tier Architecture[78]

To find the causal relationships, the case was divided into two sub-problems: blowing air or blowing nitrogen through the air blades. Hence, two respective datasets from 360 coils were prepared with 20 process variables as input (line speed, temperature etc.) and classification of the tiles as output (with or without ripple defects), depending on whether the number of defects on the tile exceeded a certain threshold. Each dataset was separated into a training and a validation set. For each case, a decision tree was built on the training data and then tested on the validation set (Figure 16). Each node represents a process variable while each branch corresponds to a range of values it can assume. The leafs represent the two classes. Following a path from the root to a leaf corresponds to a specific combination of parameters (process window) and leads to a particular classification (tile with or without ripple defects).

[78] source: Brandenburger, J. et al. (2016), p. 57 (slightly modified)

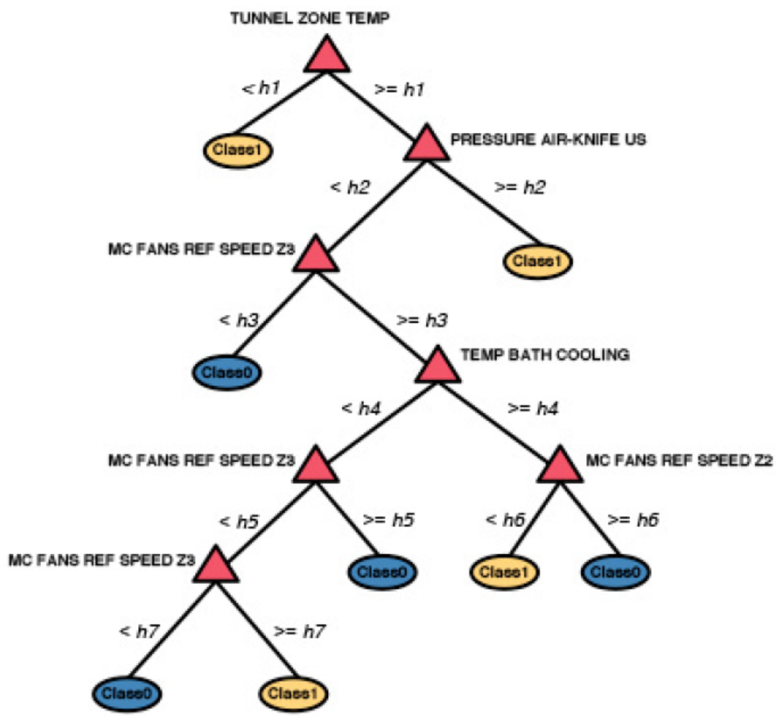

Figure 16: Decision Tree for Classification[79]

On the one hand, the importance, i.e. impact, of each process variable on the classification was calculated using the training data, which clarifies the causal relationship between parameters and occurrence of ripple defects (Table 1). On the other hand, following a specific path from root to leaf gives clear instructions on the process windows, which can easily be followed in order to achieve ripple-free products during the hot-dip galvanizing process.[80]

This is an example where more information and knowledge was generated using similar data as before, but with implementation of a different data model and architecture as well as deployment of a more advanced cause-and-effect analysis.

Table 1: Normalized Importance of each Process Parameter[81]

Air-blowing		N_2-blowing	
Air blade dist.	1	Water bath temp.	1
Tunnel zone temp.	0.69	Air blade dist.	0.46
Line speed	0.29	Hot briddle zone temp.	0.39
Air blade press.	0.25	Line speed	0.14
Fans ref. speed	0.15	Air blade press.	0.14
Top-roll zone temp.	0.08	Fans ref. speed	0.11
Water bath temp.	0.07	Air blade height	0.05

[79] source: Brandenburger, J. et al. (2016), p. 60
[80] refer to Brandenburger, J. et al. (2016), p. 59 f.
[81] source: Brandenburger, J. et al. (2016), p. 60

3.3.3 Automatic Reallocation of Non-conforming Products

Due to irregularities in the process chain, products such as hot-rolled coils fail to meet certain target specifications (e.g. thickness) and can therefore not be used to satisfy the corresponding order. These irregularities are often unforeseen and cannot fully be avoided. A multi-agent system can be used to automatically reallocate the coil to a different order which is satisfied by the achieved specifications (with or without intervening in the process and with or without post processing). Such a system consists of agents, which are “small, autonomous software programs”.[82] They have the ability to take actions which are flexible and decentral in nature as well as aimed at maximizing a specific target function. An agent can be a virtual equivalent of a product, a process or a customer order and knows about its history, its current state and can anticipate future states. For example, a product agent might know its current thickness and which production processes it underwent as well as anticipate which final thickness it can achieve given the production steps left. Furthermore, the different agents can communicate with each other and solve a common problem as a group. Finally, by introducing a service-oriented architecture, each agent gets the ability to offer its services to the system as well as utilize the services of other elements (such as accessing information and data from different databases). In order to access these services, the concerning agent has to know the structure (virtual abstraction) of the system, which it gets from a semantic agent.[83]

There are two scenarios concerning missed specifications, depending on whether the product agent can anticipate that it will miss the specifications during the process. In scenario one the non-conformity becomes only apparent after the production process has ended. After detecting that it failed to meet the specifications, the concerned product agent asks the semantic agent where to find appropriate data and retrieves said data for future decisions. It calculates all possible future processing outcomes, taking into account post-processing steps such as cutting or cold rolling, and offers all possible outcomes including the associated cost on a virtual marketplace. Order agents from the plant alone or from multiple locations across the company network join the process and start bidding, enabling to find an optimal (most economical) product-order match. The product agent initiates further processing if necessary.[84]

In scenario two the product agent detects the (future) non-conformity during the process, for example between furnace and roughing mill. First, it creates a backup plan by accessing historic data (through semantic agents), to find a common set of specification for which almost always customer orders exist. Then current order agents are requested to join the negotiation and return alternative target specifications. The optimal product-order match is calculated (based on the achievable price and cost). If this negotiation happens fast enough, the appropriate rescheduling is carried out. Otherwise the backup plan is favored. In both scenarios, the agents and associated software can be installed on multiple computers in different locations. Hence, the order agents, process agents and product agents can originate from different plants of a

[82] Neuer, M. J. et al. (2016), p. 3
[83] refer to Neuer, M. J. et al. (2016), p. 1 ff.
[84] refer to Neuer, M. J. et al. (2016), p. 4 f.

company. Overall, the system is intended to substitute intuitive solutions by the operators, which can only take into account a limited amount of data and therefore only provide sub-optimal solutions. However, human users still have an opportunity to intervene and steer the process manually.[85]

The previous chapters have described crucial elements and concepts of industry 4.0 in general as well as specific to the steel industry. The following chapters will introduce entrepreneurship and the role of startups in corporate technology and innovation management.

4 The Role of Startups in Corporate Technology and Innovation Management

Technology and innovation are of strategic relevance for industrial companies in general and for steel companies in specific. The following two subchapters will define technology, technology management and the approaches and methods as well as the equivalent concepts for innovation. The reasons to collaborate with startups and their role in corporate technology and innovation management are introduced in the subsequent chapters.

4.1 Technology Management

The English term technology originated in the 17th century and is derived from the Greek tekhnologia, which consists of tekhnē (“art, craft”) and -logia and literally means “systematic treatment”.[86] Technology (in the English sense of the word) encompasses knowledge (practical as well as practically applicable theoretical knowledge, know-how etc.) as well as the embodiment of that knowledge (physical devices, equipment, procedures, processes etc.).[87] For example if one looks at a blast furnace, technology encompasses the equipment, i.e. the blast furnace itself, the knowledge how to operate it in order to produce hot metal as well as the associated processes and procedures. The knowledge has both theoretical elements (e.g. iron oxide can be reduced with carbon and carbon monoxide) as well as practical elements (e.g. how to actually operate and control the furnace).

The overall objective of technology management is to increase and contribute to a firm’s competitiveness through planning, organizing, executing and controlling technology-related activities and aspects of the firm. It does so through procurement, development, accumulation, retention and commercial exploitation of technology.[88]

[85] refer to Neuer, M. J. et al. (2016), p. 5 f.
[86] refer to Oxford Dictionaries, https://en.oxforddictionaries.com/definition/technology (Retrieved: 04.06.2018)
[87] refer to Feldmann, C. (2007), p. 14 f.
[88] refer to Feldmann, C. (2007), p. 50 ff., Specht, D., https://wirtschaftslexikon.gabler.de/definition/technologiemanagement-50438 (Retrieved: 04.06.2018)

Technology management can be interpreted and planned as a process with three phases, the first one being identification and evaluation of relevant future technologies. For this purpose, different sources of information such as experts from research institutions, suppliers, customers, patents and research papers are solicited.[89] This is combined with supporting methods such as scenario analysis (predicting and analyzing a finite number of future states of a company's environment and context) and technology screening and monitoring.[90] Further methods include lead-user methodology (co-development of a new product or service with lead users, i.e. customers with more advanced product or service requirements), Delphi method (repeated and iterative expert survey where the interviewees get feedback about the previous survey results) and prototyping (using a preliminary product or service to incorporate customers' feedback from an early stage in the development cycle).[91] The overall goal is to discover relevant technologies as early as possible and assess their potential performance, market acceptance, technological feasibility as well as positive and negative implications.[92]

The second phase is concerned with conceptualizing and designing a technology strategy. Based on the overall strategy of a company and identification and evaluation, relevant technologies are selected and a portfolio of them is generated. Methods such as technology roadmapping (a time-based framework which illustrates the interconnection between technologies, related products and markets), investment analysis and technology calendar (a comparison between offered products and deployed technologies) are applied.[93] Decisions concern technology intensity (in products and processes) and sources of technology (internal such as research and development departments or external sources such as resource acquisition or obtaining licenses). Further decisive factors are technology protection, mode of economic exploitation (internally through process and product enhancement, externally through licensing or both) and time frame of related activities.[94]

The third phase is concerned with the execution of the strategy and therefore strongly associated with operative technology management. Planning, arranging and executing of mostly non-routine activities require project management tools as well as specific organizational forms among other things. Organizational concepts include temporal secondary structures (which operate parallel to the primary organization), project houses (dedicated spatial arrangements for a project) and research consortia (which establish cooperation across companies and research institutions). Finally, technology controlling plans and supervises future, current and past endeavors, by providing planning and information tools such as budgeting (planned allocation of resources) and

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[89] refer to Specht, D., https://wirtschaftslexikon.gabler.de/definition/technologiemanagement-50438 (Retrieved: 04.06.2018)
[90] refer to Amberg, M. et al. (2011), p. 43 ff.
[91] refer to Amberg, M. et al. (2011), p. 43 ff.
[92] refer to Specht, D., https://wirtschaftslexikon.gabler.de/definition/technologiemanagement-50438 (Retrieved: 04.06.2018)
[93] refer to Eversheim, W. et al. (1993), p. 78 ff. Phaal, R. et al. (2004), p. 9 ff.
[94] refer to Specht, D., https://wirtschaftslexikon.gabler.de/definition/technologiemanagement-50438 (Retrieved: 04.06.2018)

key performance indicators (which compress and illustrate relevant information in an aggregated form) as well as risk management tools.[95]

4.2 Innovation Management

As mentioned in chapter 1.1, innovation involves novel characteristics and elements, which can be incorporated into goods, services, processes, organizational forms, marketing methods and objects and abstract concepts in general.[96] The novelty can come from a completely new (better) version of the product, process etc. or just represents a substantial improvement. Equally important to the novel quality is the implementation or institutionalization thereof, which brings (a limited form of) permanence to and establishes the initiated modification.[97] Innovation can range from improving user experience through new product features to enhancing employee satisfaction through organizational change and raising process efficiency through renewed equipment. In addition, innovation is not limited to the business sphere: better leveraging nutritional elements of the surrounding and changing dietary habits can help mitigate malnutrition in impoverished regions of the world (an example of social innovation).[98]

The innovation process runs from the emergence of ideas to the (market) launch of a new product, process etc. and can be conceptualized in multiple ways. Figure 17 shows a linear illustration with two prominent perspectives: technology push (where innovation originates out of new discoveries in science and technology) and market pull (where a strong customer need leads to innovation). The term manufacturing points toward the fact that the illustration is modeled around product innovation. However, if the term is interpreted more widely (as in applying the found knowledge of the research and development phase), the model can also be used to describe process innovation and other forms such as introduction of new organizational concepts or new business models.[99] Furthermore, it is important to note that one might include diffusion of an innovation in the market and imitation by competitors as part of the process.[100]

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[95] refer to Specht, D., https://wirtschaftslexikon.gabler.de/definition/technologiemanagement-50438 (Retrieved: 04.06.2018)
[96] refer to Specht, D.; Möhrle, M. G., https://wirtschaftslexikon.gabler.de/definition/innovation-39624 (Retrieved: 19.05.2018)
[97] refer to Eurostat et al. (2005), p. 46 ff.
[98] refer to Brown, T.; Wyatt, J. (2010), p. 31 ff.
[99] refer to Trott, P. (2005), p. 22 ff.
[100] refer to Feldmann, C. (2007), p. 45 f.

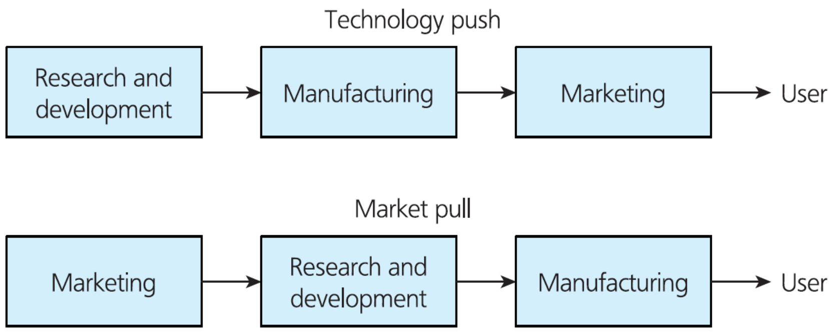

Figure 17: Linear Illustration of the Innovation Process[101]

Innovation management is aimed at increasing a firm's value and contributing to its competitive position in the market, just as other parts of the management system. Aligned with the overall business strategy, it guides the company through the innovation process and adjacent fields, on strategic and operative levels. Innovation management specifies the overall principles which encompass all activities related to innovation and engages in other strategic initiatives such as setting long-term goals, plans and coordination as well as strategic controlling. It also does that on an operative, i.e. short- and medium-term basis and engages in related finance and human resource activities.[102] Furthermore, it deploys a range of concepts, instruments and tools such as prototyping (testing user acceptance and other characteristics on a preliminary product), TRIZ (Theory of Inventive Problem Solving, a set of methods to generate innovation; for example TRIZ evolution trends, a technology forecasting tool) or gatekeeping (establishing "go/kill decision points"[103] in the innovation process, to focus resources on the right projects).[104]

Important is the distinction between incremental innovation (improvements within a predetermined framework of solutions) and radical innovation (changing the framework altogether). The latter refers to doing something which was not done before while the former refers to improving current activities.[105] The introduction of industry-4.0 technologies is often associated with radical innovation, the introduction of new business models and change of the value chain in a particular industry.[106] Overall, innovation management includes technology management as a subfield. They have significant overlap and dependencies and are both paramount to a company's strategy, performance, competitive position and long-term success.

[101] source: Trott, P. (2005), p. 23
[102] refer to Feldmann, C. (2007), p. 49 f.
[103] Cooper, R. G.; Edgett, S. J. (2012), p. 50
[104] refer to Trott, P. (2005), p. 490 f. Vidal, R. et al. (2015), p. 202 f.
[105] refer to Norman, D. A.; Verganti, R. (2014)
[106] refer to Schatz, A.; Bauernhansl, T. (2017), p. 248 ff.

4.3 Reasons for Corporate Inertia and Inability to Radically Innovate

As mentioned in chapter 4.2 encouraging the right kind of innovation is of strategic importance for a firm's value and competitive position. However, there are a number of factors, explained in the following paragraphs, which hinder innovation in established companies and create forms of corporate inertia (Figure 18). Among other factors like gaining strategic insights into new technological fields, these can encourage established companies to collaborate with startups.[107]

Figure 18: Hindering Factors for Corporate Innovation[108]

Information filters and distorted perception effects how new data, information and knowledge is interpreted. The dominant logic in an organization may lead to intellectual uniformity and attention being focused on certain aspects while others are filtered out.[109] This can hinder innovation as relevant new opportunities may be overlooked on purpose or simply not recognized at all. This lack of absorptive capacity is particularly detrimental if technological innovation causes discontinuity and change in the competitive environment of a company.[110] Established companies also tend to focus more on innovating incrementally and increasing efficiency of established processes instead of changing the fundamentals of their business practice if necessary.[111] The intensity of this focus is influenced by firm size, internal competition and internal autonomy, influence of product champions (a person who promotes a product internally and externally) as well as market orientation.[112] Exploiting a current business model and increasing efficiency may also be accompanied (and fostered) by organizational

[107] refer to Thieme, K. (2017), p. 28 f.
[108] source: Thieme, K. (2017), p. 28
[109] refer to Bettis, R. A.; Prahalad, C. K. (1995), p. 7
[110] refer to Hill, C. W. L.; Rothaermel, F. T. (2003), p. 260
[111] refer to Thieme, K. (2017), p. 29
[112] refer to Chandy, R. K.; Tellis, G. J. (1998), p. 476 ff.

routines and bureaucratic structures. These layers of formalization and administration slow down innovation and may hinder radical innovation altogether.[113]

An additional factor is resource dependency, which refers to the fact that shifts in strategy and changes in the firm's value chain are often accompanied by the need for new resources such as suitable suppliers. The embeddedness of a firm in its current value chain may therefore limit its flexibility and tendency towards radical innovation.[114] Also detrimental is the fear of cannibalization, which describes the phenomenon that new (innovative) products and services reduce sales of established products and the value of associated investments and skills. Furthermore, inertia can be caused by political deadlocks, which emerges when different parties in the company (such as departments or divisions) have opposing views on a subject matter or differing vested interests.[115]

Promoting new products and services is associated with risks (such as failure in acceptance by the market). Independent entrepreneurs have a higher incentive to bear this risk as the rewards of a potential success are high. In case of a firm-intern innovator these rewards may be captured by the company though. Hence, the incentive to initiate an innovative project and bear the associated risk is smaller which leads to a lack of entrepreneurial culture.[116] Finally, innovation can also create the need for specific capabilities, which are not yet present in the company. The acquisition of these capabilities can take time and also leads to corporate inertia.[117] Engaging with startups can stimulate innovation and contribute to overcoming the mentioned obstacles. Therefore, it may be of key strategic relevance as it allows a company to adapt to radical innovation which changes the fundamentals and competitive environment of an industry.[118]

4.4 Definition of the Term Startup

The term startup can be explained by introducing the concepts exploration, which refers to finding new economic opportunities, and exploitation, which refers to taking economic advantage of old certainties. Exploration is among others associated with search, experimentation, flexibility, play, uncertainty, risk taking and discovery. On the other hand, exploitation is associated with implementation, execution, efficiency, certainty and refinement.[119] Startups are engaged in exploring and searching, in particular for new business models, and hence include a form of innovation (the minimum of it being the newness of the business model). In contrast, established companies (or "corporates") are engaged in exploiting an already proven business model. This makes a startup company a temporary organization. In case of failure, they cease to exist. If the business model proves successful, the startup will most likely turn

[113] refer to Chandy, R. K.; Tellis, G. J. (2000), p. 3 f.
[114] refer to Hill, C. W. L.; Rothaermel, F. T. (2003), p. 261 f.
[115] refer to Thieme, K. (2017), p. 30
[116] refer to Chandy, R. K.; Tellis, G. J. (2000), p. 4 ff.
[117] refer to Thieme, K. (2017), p. 31
[118] refer to Thieme, K. (2017), p. 28 f.
[119] refer to March, J. G. (1991), p. 71

into an established company as it focuses more on exploiting the business opportunity as efficiently as possible.[120]

Besides the newness of the business model Steve Blank, a leading entrepreneur and academic in the field, also includes scalability and repeatability as crucial criteria.[121] Other authors also add the element of fast growth.[122] Furthermore, a startup does not have to be technology-focused as the associated innovation can also emerge in other areas and not every new company is a startup. There are dozens of examples where a new company is established to execute on an old and proven business model.[123] The working definitions go therefore as follows: *A startup is a temporary, innovative and growth-focused organization in search of a new, scalable and repeatable business model. An established company or corporate is a permanent and efficiency-focused organization executing an already proven business model.*

4.5 **Types of Corporate-Startup Interaction and Associated Reasons**

There are various reasons why corporates want to engage with startups. Beyond helping to overcome the factors of corporate inertia, a strategic reason can be to support and stimulate the company's ecosystem of suppliers, customers, researchers and technology entrepreneurs by providing any kind of support to startups with an appropriate focus. This can be particularly important if crucial areas of the supply chain are underdeveloped.[124] Engaging with startups can also create and stimulate an entrepreneurial culture among employees to be more risk-taking and try new things, which may enhance the innovation capabilities and environment. It can also help to attract entrepreneurially minded talent and foster an innovative image as well as the development of back-up technologies and business models.[125]

There are multiple ways for corporates to engage with startups. Figure 19 shows the main types of corporate-startup engagement including the main reason for each option (from a corporate perspective). It also indicates whether the established company is an equity holder, i.e. part owner, in the startup and whether the innovation flow is directed outwards or inwards.[126]

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[120] refer to Blank, S., https://steveblank.com/2014/03/04/why-companies-are-not-startups/ (Retrieved: 11.06.2018)

[121] refer to Blank, S., https://steveblank.com/2014/03/04/why-companies-are-not-startups/ (Retrieved: 11.06.2018)

[122] refer to Graham, P., http://www.paulgraham.com/growth.html (Retrieved: 11.06.2018); Kohler, T. (2016), p. 348

[123] refer to Graham, P., http://www.paulgraham.com/growth.html (Retrieved: 11.06.2018)

[124] refer to Campbell, A. et al. (2004), p. 30 f.

[125] refer to Thieme, K. (2017), p. 32

[126] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 81

Equity Involvement	Direction of Innovation Flow: Outside-In	Direction of Innovation Flow: Inside-Out
Yes	**Coporate Venturing** Participate in the success of external innovation and gain strategic insights into non-core markets.	**Corporate Incubation** Provide a viable path to market for promising corporate non-core innovations.
No	**Startup Program (Outside-In)** Insource external innovation to stimulate and generate corporate innovation.	**Startup Program (Platform)** Spur complementary external innovation to push an existing corporate innovation (the platform).

Figure 19: Main Types of Corporate-Startup Interaction[127]

Corporate venturing or corporate venture capital is direct or indirect investment of financial resources in startups in order to acquire equity stakes.[128] One reason to do so is to generate a positive financial return and economically benefit from the upswing in particular technology fields.[129] In addition to financial gains, the established company also gains strategic insights and access to new markets and complementary products and technologies. This is particularly important in areas which are anticipated to be of strategic relevance to the company in the future and where the existing expertise and skills in the company are not sufficiently developed yet.[130] It can also influence decisions of the startup and has a favorable position to fully acquire it if desired. From the startup’s perspective, this type of engagement brings key resources such as capital, technical and market insights, access to specialized equipment and assets as well as enhanced credibility in the market. However, it limits the access of the venture towards a diverse set of resources from an open market, in particular with respect to competitors of the corporate.[131] Furthermore, it might expose the startup to a hidden agenda of the investor and the strategic goals of the corporate might be opposed to the startup’s objectives.[132]

Corporate incubation is a way to exploit innovation which are born inside the company but do not fit the core business, by founding appropriate outside ventures. It usually includes a project environment outside of the parent organization and provides support in the form of initial funding, co-location, contacts and access to equipment and expertise. The intention is to provide the founding team with a setup which is outside of the parent organization, in order to avoid corporate inertia and enable radical innovation. In light of the technological proximity, many resources can be shared and increase the chances of success for the startup. This form of corporate-startup interaction also makes sense if a company has under-utilized resources or

[127] source: Weiblen, T.; Chesbrough, H. W. (2015), p. 81
[128] refer to Thieme, K. (2017), p. 33
[129] refer to Campbell, A. et al. (2004), p. 34 ff.
[130] refer to Hill, S. A.; Birkinshaw, J. (2008), p. 424 ff.
[131] refer to Park, H. D.; Steensma, H. K. (2012), p. 2
[132] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 70 f.

technologies, i.e. those which are not fully commercially exploited yet.[133] Disadvantages are potential overprotection by the parent organization (increasing the cost of a potential failure), limiting the startup with respect to partnerships with the parent's competitors, and with respect to developing competing products.[134]

The aim of outside-in startup programs as a third category is to make relevant startup technologies and products available inside the established company and profit from external innovation. The formal organization of such a program can be structured in multiple ways and can also vary from one startup to another. One form is a co-working location to benefit from the close proximity with innovative ventures. Corporate accelerator programs are another option and are aimed at assembling relevant startups for a specific time in a structured way. Other forms are pitching events (where startups present their idea and work), joint projects of startup and corporate employees, licensing the technology and employing the inventor to bring it to maturity inside the established company as well as other forms of non-equity partnerships.[135]

Again strategic insight in and access to new technologies and corresponding markets is a relevant factor. The main motivation is to extend the current business into areas with high growth potential, to identify radical innovation early and help to commercialize them.[136] Furthermore, startups can help to improve and innovate on existing products and services of the firm as well as internal processes by providing new and complementary technologies, which enhance the firm's resources.[137] From a startup's perspective, access to corporate resources (such as expertise, equipment and market access) is helpful as well as the credibility gain by adding the corporate to its customers. Furthermore, the project-based approach avoids the same form of dependency as corporate venture capital and established programs can help to overcome other difficulties (such as exhausting vendor qualification processes). However, if not managed properly, intellectual property can become a substantial risk factor and startups could worry that corporates steal their ideas and technology.[138]

Finally, platform startup programs try to harness the benefit of platform innovation, which occurs if a set of companies produce complementary products and thereby strengthen the common platform. The goal is to get startups developing their products using their platform so that the corporate can establish itself as platform leader and profit from the developed innovation. It is a standardized approach to engage startups and help them develop their products on the platform, in order to benefit from their speed of innovation and startup's inherent support for the corporate as platform leader. Another advantage is to gain future customers through the startups' channels. On the other hand, the startups get access to necessary resources which would not be attainable otherwise. A prominent example would be a startup developing an app and using Apple's iOS or Google's Android platform. A risk factor is that the startups are

[133] refer to Campbell, A. et al. (2004), p. 32 ff.
[134] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 71 f.
[135] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 72 ff.
[136] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 72 ff.
[137] refer to Thieme, K. (2017), p. 31 f.
[138] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 76 f.

locked in with the platform provider, unless they are willing to spend the resources on a multiple-platform approach.[139]

[139] refer to Weiblen, T.; Chesbrough, H. W. (2015), p. 77 ff.

5 Summary

The aim of the research endeavor was to identify startups' role and technical implications in the field of industry 4.0, specific to the steel industry. Industry 4.0 has been defined as a future state of industrial process chains which are characterized by horizontal and vertical integration as well as integration between the virtual and the physical state. Furthermore, the technologies which enable and which are enabled by this state are included. Digitalization in the steel industry, the sustained development to achieve this, necessitates a further and strong integration of ICT into metallurgical process chains, which could offer opportunities for startups in this field.

The research approach was to conduct a literature review of industry 4.0 and the associated technological concepts in general. Furthermore, specific examples of relevant applications in the steel industry were investigated. To understand the role of startups in corporate strategies, key concepts in technology and innovation management, reasons for corporates' inertia to radically innovate and modes of corporate-startup collaborations were explored.

A major finding of the research was that the technological complexity of industry 4.0 in the steel industry is enormous. This is due to the fact that the already very long, heterogeneous and complex metallurgical process chain has to be combined with ICT concepts such as machine learning which are also complex.

Entrepreneurship and corporate-startup interaction can be a substantial resource in accelerating innovation. On the one hand, this could be driven by the corporate side through one of the four interaction modes (corporate venturing, corporate incubation, outside-in or platform startup program). As industry-4.0 technologies are very new to steel companies and not their core business, the innovation flow has to be outside-in, which means that either corporate venturing or a startup program would be adequate. However, the innovation could also be driven by the startup in which case a customer service relationship with elements of co-development of a solution makes sense.

The assessment of the author is that the visions associated with industry 4.0 will still take some time to be implemented in the steel industry. The reason is not so much a conservative mindset. It is rather the complexity of the topic which slows down progress. In comparison to discrete industries (such as automotive), continuous process chains make it harder to implement key concepts of industry 4.0 such as smart products. Although it will take a longer time, the opportunities associated with digitalization are large and have the potential to fundamentally change metallurgical value chains.

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