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Master Thesis

# THE FUTURE OF PURCHASING AND INDUSTRY 4.0:

How Purchasing can Progress and Benefit the Fourth Industrial Revolution

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Hereby I would like to express my thanks to my supervisors for giving me the opportunity to write this master thesis with them and their support throughout the process. I admire the internal drive and work ethic of both Dr. Pulles and Prof. Dr. Schiele. Their enthusiasm and perseverance has inspired me to follow in their footsteps by pursuing an academic career.

When Industry 4.0 was introduced to me during a lecture in autumn 2016, the topic immediately drew my attention. To me, Industry 4.0 feels like a train that is ready to leave the station, and I want to board this train to experience the ride, and contribute to shaping its destination along the way.

Writing this master thesis has been a long-lasting journey with the corresponding ups and down. In hindsight, I would have done many things differently, but I consider that part of the growth process.

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**LIST OF ABBREVIATIONS**

| | |
|---|---|
| BDA | Big Data Analytics |
| CPS | Cyber-Physical Systems |
| ERP | Enterprise Resource Planning |
| I4.0 | Industry 4.0 or The Fourth Industrial Revolution |
| ICT | Information and Communications Technology |
| IoS | Internet of Services |
| IoT | Internet of Things |
| IIoT | Industrial Internet of Things |
| IT | Information Technology |
| M2M | Machine-to-Machine communication |
| MRP | Materials Requirements Planning |
| PCB | Printed Circuit Board |
| RFID | Radio Frequency Identification |
| WSN | Wireless Sensor Network |

# 1. THE FOURTH INDUSTRIAL REVOLUTION: EXPECTED TO INCREASE INSIGHTS IN SUPPLY CHAINS

## *1.1. Information technology drives the engines of tomorrow's factory*

Imagine a well-lit hall with a glossy polished floor reflecting the lighting from the ceiling, which is supported by clean white metal beams[1]. The cleanliness of the massive hall and the absence of noise, except for humming computers, reminds of images of sterile operation rooms in hospitals. At the ceiling, a bridge crane mounted at the roof beams slides back and forth to lift and load raw materials. On the floor, countless robotic arms assemble components of complex products in the making. Autonomous guided vehicles carry parts and finished products to supply the construction robots with the required materials on the exact time needed. The goods manufactured in the production hall differentiate apiece in functionality and appearance, based on preferences determined by individual customers.

Extensive monitoring and communication between machines allows for real time changes, even during the production process, to correct errors or apply customisation. Owing to advanced analytics, schedules are continuously optimised autonomically and in real time to minimise energy consumption. Prior to production, goods and services are acquired from suppliers that are closely involved throughout the product's lifecycle. The inclusion of suppliers means relevant data from the mining of raw materials to the disposal of obsolete products can be analysed and shared vertically within the supply chain via connected computer systems. These wide-ranging analyses may serve as the foundation purchasing managers base their decisions on towards innovation, growth, and cost-savings.

## *1.2. Industry 4.0: Everyone in the industry is talking about it, but no one knows how to do it*

The described scenario depicts a possible implementation of Industry 4.0, also known as I4.0 or the fourth industrial revolution.  The basic principle of I4.0 compromises connecting value adding physical elements of supply chains to the internet. Incorporating technology in manufacturing is expected to improve value creation because adopting information technology

[1] Based on Tesla, unknown author (2014).

(IT) will require the restructuring of operations towards standardised processes to improve their responsiveness[2].

Although the concept Industry 4.0 echoes through the corridors of firms in the manufacturing industry, knowledge on how to apply its distinctive characteristics resides in a premature stage. The maturity of implementing I4.0 is emphasised by the following statement from a purchasing executive in the German automotive industry: *"Everyone is talking about it [Industry4.0], but no one knows how to do it."* Most firms started implementing I4.0 one way or the other. However, in this manager's perception, every company interprets the concept of I4.0 differently. Thus, to achieve consensus on the meaning of Industry 4.0, a general definition will clarify its features and boundaries.

Presently, several definitions of I4.0 circulate, varying in length and focus, but in conformity with an expected connection between the cyber- and the physical world. Bitkom, Germany's digital association that represents over 2,400 companies in the digital economy, employs the following definition: *"Central to Industry 4.0 is the possibility to connect people, machine, objects, and ICT-systems intelligently and in real time to manage complex systems dynamically."* [3] The consulting firm McKinsey defines 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 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."*[4]

At the end of this chapter, our own definition of Industry 4.0 is presented. The definition is based on the keywords that are most often mentioned in scientific articles on the subject I4.0.

[2] See Belvedere et al. (2013), p. 423.
[3] Bauer et al. (2014), p. 18.
[4] Baur/Wee (2015).

*1.3. Growing interest from the industry and academics propels Industry 4.0*

History distinguishes three industrial revolutions: the transition from manual labour to mechanisation (1), electrification (2) and digitalisation (3)[5]. Industry 4.0 is generally regarded as the successor of the three industrial revolutions by researchers[6]. The literature describes parallels between historical industrial revolutions and their modern counterparts[7] and the tangible legacy of technological changes during the second industrial revolution[8]. Remarkably, unlike earlier industrial revolutions, Industry 4.0 is proclaimed an industrial revolution already before it has taken place[9]. Nevertheless, interest in this technological upheaval is growing[10].

Industry 4.0 was announced at the 'Hannover Messe' in Germany in 2011[11] by communicating the statement that implied the production industry resides on the verge of an extensive change again and relies on so-called 'smart manufacturing'[12]. Production 4.0 encloses Smart-Factories, housing flexible and reconfigurable manufacturing systems[13], enabling tailored manufacturing with lower lead times[14]. This upheaval in the manufacturing industry is expected to bring the benefits of the internet and advances in information technology to the industry sector[15]. The principle consists of integrating the internet with supply and production, thereby connecting the digital world with the physical world. This connection is projected to be established through Cyber-Physical Systems (CPS)[16].

The existing literature on the fourth industrial revolution mainly takes an engineering perspective[17] where attention is paid to implementing new technologies in manufacturing[18]. From a computer science viewpoint, the literature provides among others a description of the

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5 See Drath/Horch (2014), p. 56.
6 See Jazdi (2014), p. 1; Lasi et al. (2014), p. 239; as well as Lee et al. (2014) p. 3.
7 See Jensen (1993), p. 831-833.
8 See Mokyr (1998), p. 13.
9 See Drath (2014), p. 2.
10 See Li et al. (2017), p. 23.
11 See Hermann et al. (2016), p. 3929; Kang et al. (2016), p. 112.
12 See Kang et al. (2016), p. 111-112.
13 See Wang et al. (2015), p. 158-159.
14 See Wan et al. (2015), p. 135-136.
15 See Weyer et al. (2015), p. 579.
16 See Lasi et al. (2014), p. 240.
17 See Scopus (2017a).
18 See Wan et al. (2015), p. 135-140; Wang et al. (2015), p. 158-168.

usage of intelligent sensors[19], an overview of recent trends[20] and an architecture for implementing Cyber-Physical systems[21]. The research category business and management is also represented in the literature, but most publications on Industry 4.0 originate from computer science or engineering[22]. The arrangement and origin of the literature on I4.0 is illustrated in Chapter 3, including an analysis of publications on I4.0 and related topics.

The manufacturing industry is taking notion of I4.0 as well, as illustrated by the following three results. First, a survey by PricewaterhouseCoopers of 235 German industrial firms, shows that in the next five years, companies will invest 3.3 percent of their annual turnover in Industry 4.0 applications[23]. Second, the Boston Consulting Group, estimated an increase in productivity of five to eight percent regarding total manufacturing costs, by firms adopting I4.0[24]. Third, the Fraunhofer society expects a cumulative added value potential of 23 percent between 2013 and 2025, dispersed across six industries within Germany alone[25]. Although these numbers represent German figures, while nowadays many countries investigate in digitizing their production industry[26], the expected financial potential of I4.0 is generalizable, because Germany is indisputably an industrial heavyweight by generating around 33 percent of added value of the EU's industry[27].

### *1.4. Industrial revolution: a rapid rise in industrial output due to a transition in manufacturing processes*

Due to the many stakeholders and their accompanying investments in I4.0, large interests are at stake to redeem the promise of the fourth industrial revolution. Organizations and research institutes have widely adopted the concept of the fourth industrial revolution. Thus, to investigate whether this agitated technological leap is rightfully sided with the three preceding industrial revolutions, a definition of Industrial revolutions is presented. Chapter 2 will describe

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[19] See Jazdi (2014), p. 2.
[20] See Lee/Lapira (2013), p. 4-7.
[21] See Lee et al. (2015), p. 19-20.
[22] See Scopus (2017a).
[23] See Koch et al. (2014), p. 7.
[24] See Rüßmann et al. (2015), p. 2.
[25] See Bauer et al. (2014), p. 39.
[26] See Stolwijk/Butter (2015), p. 5.
[27] See Heng (2014), p. 1.

the three industrial revolutions and their characteristics regarded as revolutionary by referring to the following definition.

Crafts (1977) defined an industrial revolution as: *"a period of accelerated structural change in the economy, involving a rapid rise in industrial output, in the share of manufacturing in national product, and in factory-based activity (implying a different kind of economy), based on major technological innovations."*[28]

Although Crafts' definition implies a rapid transition to new and more efficient manufacturing processes, it ignores the accompanying organisational changes, for instance more efficient factory layouts, that were facilitated by these new methods of production. Chapter 2 will elaborate further on the organisational changes conforming the key technologies that each industrial revolution introduced.

### *1.5. Industry 4.0 in purchasing: knowledge is desired to redeem its promising expectations*

Despite increasing interest, currently, knowledge on how to transform current operations to satisfy future needs in manufacturing and purchasing, is lacking. Still, the predictions are that the fourth industrial revolution challenges manufacturers to review their current operation procedures[29]. Specifically, I4.0 faces the challenge of establishing a common approach based on common basic terminology by incorporating existing standards derived from automation, with the goal of building a global foundation for I4.0[30].

Complementary to the challenge of an absent foundation, merely embracing new opportunities by solitarily collecting Big Data, will not enhance the competitiveness of manufacturers. To come along with the transition, this continuous stream of information from Big Data should be presented in a meaningful context which provides firms the essential insights to base their decisions on.[31] For firms considering adopting Industry 4.0, especially purchasing is expected to benefit from analysing data and using it smartly[32]. Although firms started experimenting with implementing I4.0 in production, the current condition of procurement 4.0 resides in its initial

[28] See Crafts (1977), p. 431.
[29] See Wang et al. (2016), p. 1.
[30] See Kagermann et al. (2013), p. 40.
[31] See Lee et al. (2013), p. 38.
[32] See Geissbauer et al. (2016), p. 8.

phase. Thus, because of the expected financial potential of Industry 4.0 and particularly its application in purchasing, research how purchasing can support the introduction of I4.0 generates valuable insights for the industry.

By adopting a multidisciplinary approach, this paper integrates insights from previous studies from a variety of research fields. Our contribution to the existing literature in the field of purchasing with Industry 4.0 is two-fold, with relevance for both research and practical applications. First, an agenda with topics for future research is presented. Second, a maturity model is developed for purchasing managers.

This thesis starts with an analysis of the four industrial revolutions by describing their distinctive characteristics. Subsequently, a literature review on I4.0 is provided to gain insights in the current literature and to identify trends. Thereafter, two chapters continue with our proposed research agenda and the maturity profile. Closing, a conclusion that answers the research questions is provided.

This paper aims to answer the following research questions:

RQ 1: Which characteristics defined the three industrial revolutions preceding Industry 4.0 as revolutionary?

RQ 2: Which attributes qualify Industry 4.0 as an industrial revolution?

RQ 3: Which enabling technologies are currently associated with Industry 4.0?

RQ 4: What is the current state of art of the enabling technologies supporting Industry 4.0?

*1.6. Industry 4.0: highly automated manufacturing processes facilitated by Machine-to-Machine communication and Cyber-Physical Systems*

During the process of the literature study, various definitions of I4.0 passed by. Yet, a widely accepted definition of I4.0 is lacking[33]. Some definitions are unrelated to Cyber-Physical systems or lack implications for practice[34]. Our definition is based on key topics of I4.0 in the literature and thereby includes its main technologies, and the business implications following from I4.0:

*"Industry 4.0 relates to implementations of machines that make decisions autonomously, facilitated by data-driven machine-to-machine communication and cyber-physical systems that convert the analysed and communicated information to action."*

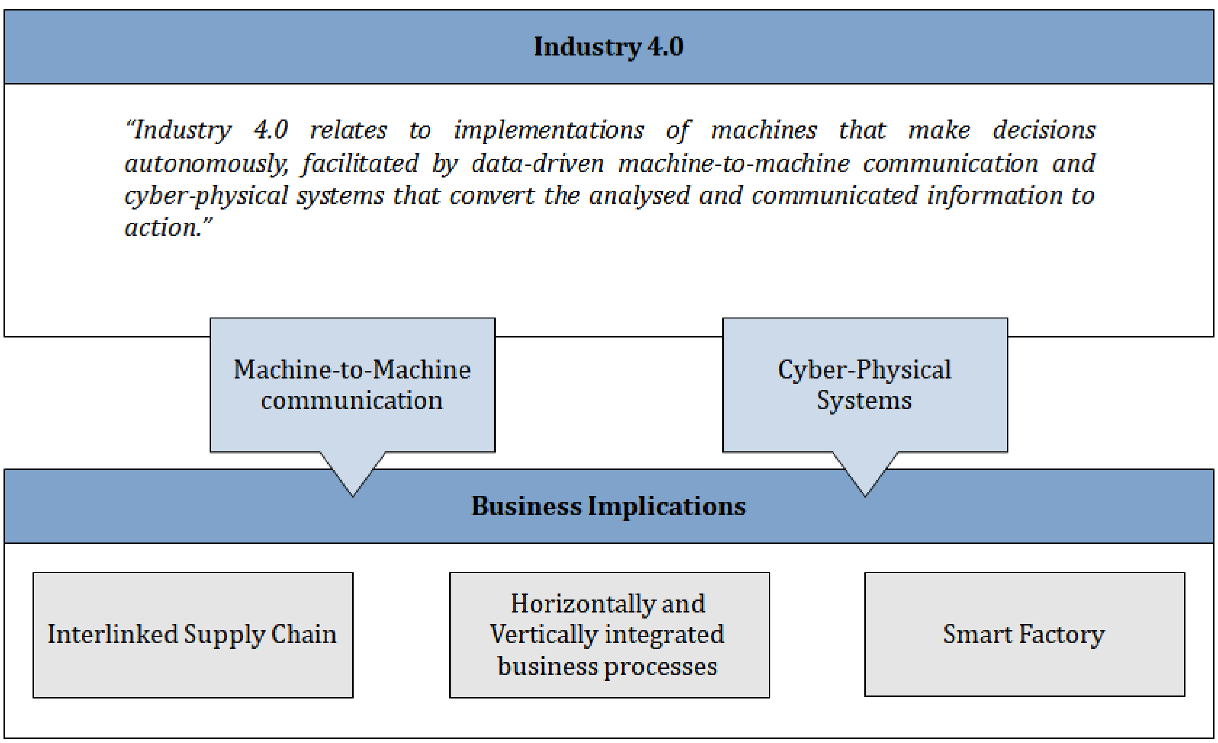


Figure 1-1 Definition of Industry 4.0

[33] See Brettel et al. (2014), p. 43; Lu et al (2017), p. 2; as well as Teichgräber et al. (2017), p. 2.
[34] See Liao et al. (2017), p. 3624.

# 2. HOW DOES INDUSTRY 4.0 STAND OUT AS A REVOLUTION?

### *2.1. Industrial revolutions: rapid transitions to new manufacturing processes*

By analysing the three preceding industrial revolutions, this chapter maps out their distinctive characteristics. Each revolution accompanied different incentives to solve the challenges of their era, supported by a technological breakthrough, the so-called ‘key technology’ of that time, and an organisational change. Consequently, Industry 4.0 is compared to the definition of industrial revolution used in this thesis.

The three industrial revolutions in modern history left their imprint on the manufacturing industry and even today’s world their influence noticeable. While the distribution of the GDP sector composition (agricultural, industrial, services) changed drastically during the last 150 years, the manufacturing industry still plays an important role with a significant financial impact in the western world. The manufacturing landscape has changed compared to days past, product variations and options for personalisation for example, have increased dramatically since Ford’s famous model T that was available in black only. Factories still exist, but their appearance and methods of operating are completely different compared to the past, because nowadays production must cope with more flexibility in both variety of products as well as production scheduling.

Ever since the 1960s and 1970s, the geographic scope of companies started growing, aided by communication technologies that made it easier to stay in touch with divisions abroad. The IT-revolution that followed during the 1980s and 1990s, accelerated the appraisal of information technology and hereby the ability to integrate supply chains nationally and globally[35]. In recent years, the possibility of extracting information from data has ended up momentum due to the universal adaptation of internet services. Coined as ‘the world’s most valuable resource’[36], customer data has become an indispensable revenue driver for tech giants Alphabet (Google’s parent company), Amazon, Apple, Facebook, and Microsoft. However, the importance applying information technology stretches beyond the boundaries of technology companies. Car manufacturer Tesla, for example, gathers data from their self-driving cars sold to customers with

[35] See Porter/Millar (1985), p. 22-28.
[36] See The Economist, unknown author (2017), p. 7.

the aim of improving performance along the way. The extensive application information technology across supply chains is expected to transform companies' way of doing business and how they compete and the boundaries of competition[37].

To come along with the tendency towards comprehensive integration of information technology across supply chains, a new paradigm of industrialisation is proposed to organisations. Concerning content, this means taking a new position on how the manufacturing industry should operate. Rolls Royce, the engine manufacturer that now earns money by selling flight hours is an example that is often of how business models can change due to new technologies. Their approach called 'Power-by-the-hour', that was invented in 1962, pioneered the servicesization of selling goods and stretched the company's focus from engineering good engines to monitoring the usage of the engine[38]. Another, more recent example that successfully expanded its operations because of information technology, is Medtronic. This medical device company developed a device for continuous monitoring of glucose that operates via a sensor, inserted under the skin, that sends information to a connected monitoring device with a display[39]. Although these two firms are active in different markets, they both could integrate service aspects within their existing business models by making use of IT.

From a board-level perspective, the extensive application of IT in supply chain activities is called digitisation. Digitisation is the transformation of business across people, technology, and processes. Different names are ascribed to this expected development, some call it the third industrial revolution[40], some the second machine age[41] and others smart industry[42]. In manufacturing this expected development is, predominantly, called Industry 4.0.

Although Industry 4.0 is a popular term that is often indicated as the fourth industrial revolution. Consensus between experts on the matter why this phenomenon is indeed a revolution, is absent. This chapter aims to answer the question: what makes Industry 4.0 a revolution? In answering the question, whether Industry 4.0 can rightfully be gathered under the denominator industrial

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[37] See Porter/Heppelmann (2014), p. 23.
[38] See Rolls-Royce, unkown author (2012).
[39] See Medtronic, unkown author (n.d.).
[40] See Rifkin (2012), p. 1-8.
[41] See Brynjolfso/McAfee (2014).
[42] See Smart Industry Workgroup (2014), p. 9-14.

revolution, the overlapping attributes of the first three industrial revolutions need to be clarified. Crafts (1977) definition of an industrial revolution, as mentioned in (1.4), puts emphasis on the rapid transition to new manufacturing processes. Much research on the financial impact of industrial revolutions on a country level is done by economic-historic researchers (e.g. Mokyr[43]). However, more relevant for this paper's purpose, is providing clarity on what Industry 4.0 is about and whether it is the next industrial revolution. Thus, the three industrial revolutions are described specifically with a narrow focus on their impact on the evolution of the manufacturing industry. Put briefly, the following four indicators can be classified as characteristics for industrial revolutions: a development of changing areas of interest in science (1) and, a demand for advanced methods for production (2), leading to an introduction of numerous inventions and technologies (3) during a short time period (4)[44].

Critical organisational shifts in firms occur simultaneously with industrial revolutions, which are subject to the four indicators that classify them as revolutions. History shows that every industrial revolution consisted of a combination of technological progress and incremental organisational changes[45]. For example, the first industrial revolution introduced the factory, followed by the debut of large modern business enterprises during the second revolution and from the 1970s, organisations became more decentralised. Conceivably, Industry 4.0 will also change how the process of how businesses make decisions and resolve issues.

### *2.2. A systematic approach of analysing industrial revolutions by classifying a prologue, a key technology and an organisational change*

To discover if Industry 4.0 is synonymous to the fourth industrial revolution, this research uses a systematic approach, analysing three unique characteristics of each industrial revolution: a prologue, a key technology, and an organisational challenge. The *prologue* refers to the driving force through which the revolution arose. For instance, difficult challenges on a national or global level, (i.e. improving competitiveness, stimulating economic growth or acting upon a changing environment). *Key technology*, illustrates the main technological advancements that led to a breakthrough. *Organisational change* describes the changes that went together with

[43] See Mokyr (2005), p. 285-351.
[44] See Jensen (1993), p. 831-833; Mowery/Rosenberg (1991), p. 23-28.
[45] See Kapás (2008), p. 15-16.

adopting the technological advancements. In this research, organisational changes consist of two elements: a change of operations (1) and a change in management style (2), that is better suited to adopt the new way of working. Adjustments of management styles are often overlooked in analysing industrial revolutions, but these changes aimed at people, are crucial in adopting extensive alterations effectively. The framework below gives an overview of how an occurrence on a global level leads to the development of a *key technology* and thereafter its implementation through an *organisational change*.

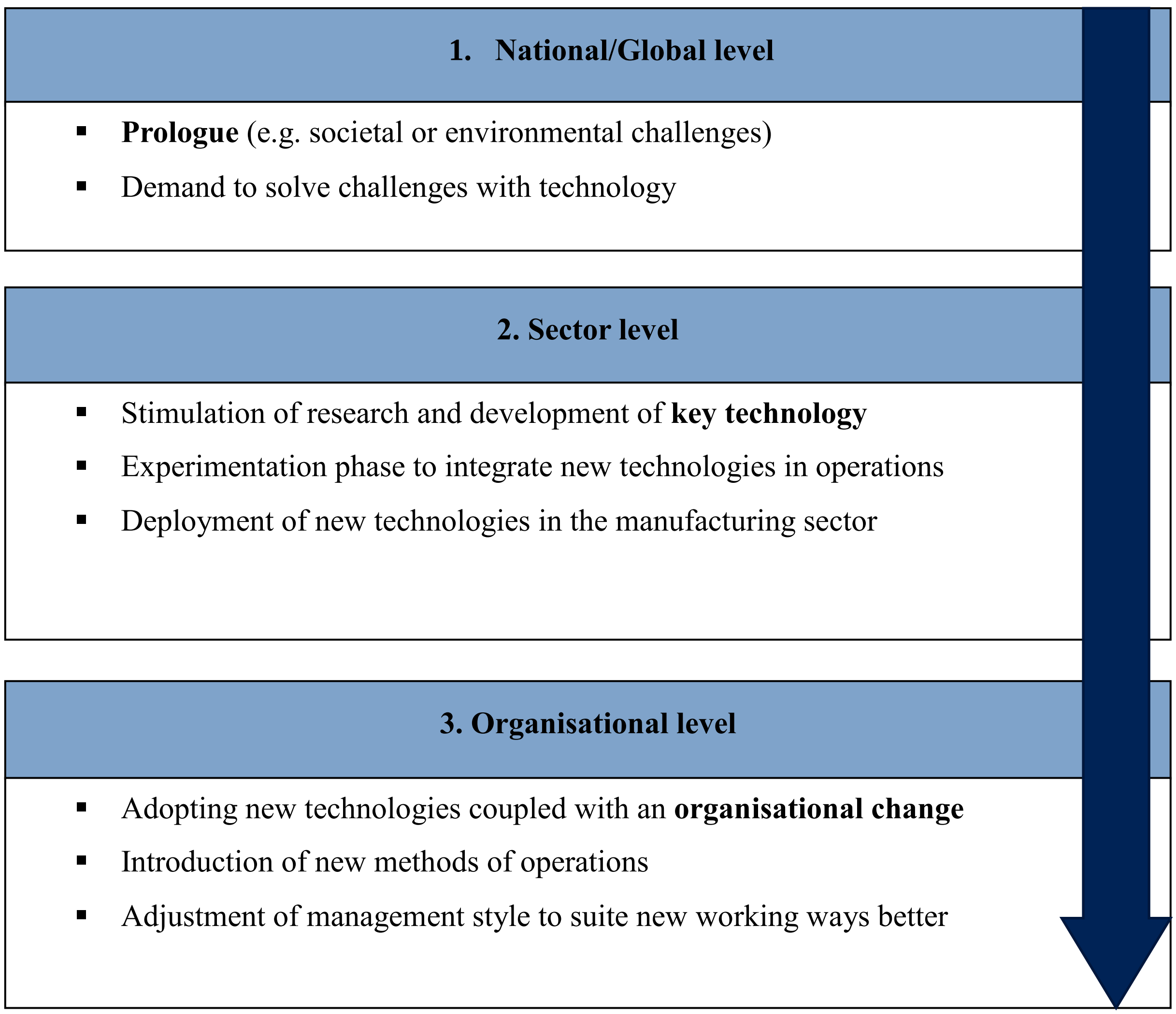


Figure 2-1 Framework characteristics industrial revolutions

The following part is divided in four sections, each describing a consecutive industrial revolution. Though, the transformations took place in a period of two-hundred-fifty years, they share similarities with each other. In earlier research, the parallels between the modern and historical industrial revolution are described as prevalent technological and organisational reformations leading to lower costs, increasing average but decreasing marginal productivity of labour and excess capacity[46]. The first industrial revolution is described in (2.2), next the second in (2.3), then the third in (2.4), and finally the fourth revolution in (2.5). Thereafter, an overview of their identifying marks and a conclusion on the fourth industrial revolution is presented in (2.6).

## *2.3. The first industrial revolution: the mechanisation of labour*

### 2.3.1. *Prologue: Manufacturing moved from the country side to centrally located factories*

Preliminary to the first industrial revolution, starting in eighteenth century's England, a short agricultural revolution took place. During the agrarian revolution, more effective ploughs were invented which had the benefits of cutting labour costs and saving time. Then, the Dutch four crop rotation system was introduced which enabled agrarians to make better use of the available farming land. Because of these improvements in farming the yield of the land rose, so there was excess food whereupon the population started growing. Contrary to before, less people were needed to produce more food. Hence, a comprehensive migration from rural England to its cities began. Factory owners gratefully welcomed the urbanisation since it led to a surplus of cheap labourers and lower production costs. Although the growing population stimulated the demand for textile products, the lion's share was exported to foreign countries by undercutting competition on price. Thereby, British textile manufacturers had redeemed the need to capture the worldwide textile industry.

The first industrial revolution is built on the foundation of three technological breakthroughs: the invention of a new power source (1), the expansion of the infrastructure by the construction of railways (2), and new machine tools, the instruments of industrialisation (3).

Not long after its introduction, the steam engine, developed by Newcomen in 1712 and improved by Watt around 1770[47], was housed in many large halls across the country. Production shifted from craft-shops in the countryside to factories in large cities. Steam was not the only

[46] See Jensen (1993), p. 831.
[47] See Frenken/Nuvolari (2004), p. 421.

energy source in those days. Machines driven by water or wind energy were implemented successfully as well. However, because steam machines were less dependent on environmental factors, which gave manufacturing more autonomy to place factories on more centrally located places. Centralising production facilities on practical locations, independent of natural energy sources was the logistical contribution to the productivity growth. Steam machines became the symbol for initiating the transition from manual to mechanical labour and thereby the key technology of the first industrial revolution.

### 2.3.2. *The direct drive: the implementation of steam engines in factories*

Introducing machine power in manufacturing changed how production processes operated. Since it was the first time in history that a comprehensive cooperation between man and machine took place, examples of best practices did not exist. Thus, the production processes in factories in the time of the first industrial revolution left room for optimisation. Nevertheless, the achieved production growth production was impressive. Due to support by technological inventions, industrial output rose exponentially from 1760 to 1820[48].

During the first industrial revolution, it was common that factories operated from a single centrally located power source, such as a water wheel or a steam engine. To this power source, production machines were linked directly by means of a mechanical connection. Figure 2-2 illustrates the functioning of the direct drive. The prime mover drove the line shaft, which distributed power, via pulleys and belts (A), to its countershafts along the ceiling, parallel to the central line shaft. Then, the rotation of the shaft was adjusted by gears to the required rotational speed (B) and assigned to the machine tool (C).[49]

[48] See Crafts/Harley (1992), p. 712.
[49] See Devine (1983), p. 350-353.

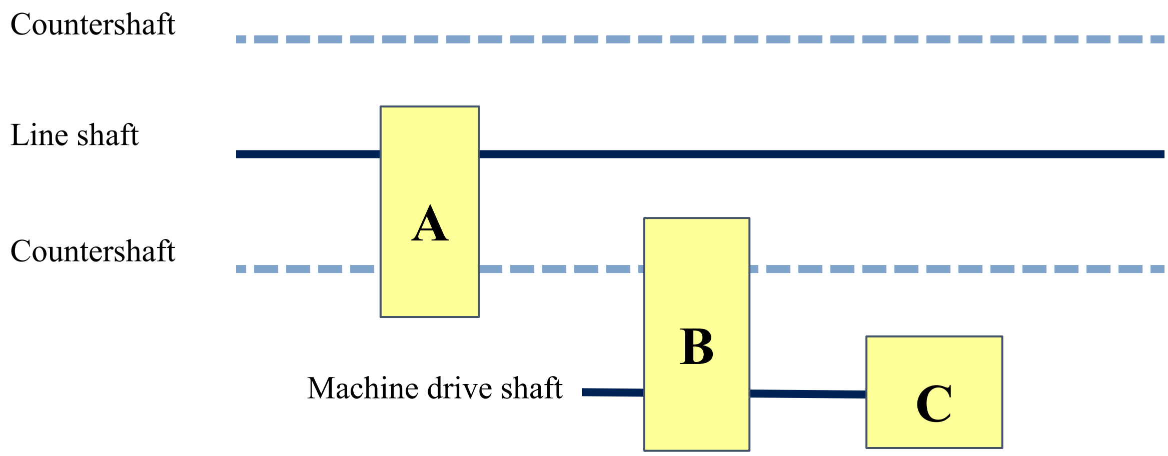


Figure 2-2 Direct drive used during the first industrial revolution

Although the machines accelerated time consuming tasks for production, there were still many workers needed to operate them, as well as for simple tasks such as the transport of raw materials and finished goods. Thus, as their task required little training, most of the workforce in factories was essentially low educated, except for a few engineers that designed and maintained the machines. Given the high degree of specialisation and the dependency on experts that was needed to keep the machines running on one hand, and the exchangeability of workers for daily operations on the other hand, the extent of influence on decisions differed much between employees. This created working environment with authoritarian leadership where knowledge of operations was in the hands of a few people that became specialists of the company. Hereby, labourers ended up in situation that was comparable to the time when peasants worked on the farmlands of the land owners. Thus, while industrialisation led to great improvements of the way of working in manufacturing, the style of management was largely unchanged and remained its character of a large power distance between owners and subordinates.

### *2.4. The second industrial revolution: scaling up the factory*

#### 2.4.1. *Prologue: The second industrial revolution focused on improving efficiency in manufacturing*

Although the introduction of the steam engine stood at the cradle of inventions, such as locomotives and steamers, which set the stage for international trade, a second industrial revolution vastly improved the efficiency of production. The next major leap forward occurred in 1870 and lasted until 1914, the start of the first World War[50]. In contrast to the first industrial revolution, the concepts introduced during its successor are more clearly noticeable nowadays. The search for improvement advanced from experimentation to a systematic approach during the second period of industrialisation, indicating that the manufacturing industry matured.

The second revolution accelerated innovations via the amplified cooperation between technology and science, meaning the role that luck played, decreased, while the use of relevant gathered knowledge rose. By focusing on solving real problems instead of wasting energy on things that do not work, like perpetuum mobiles and alchemy, the industry advanced. As an example, the problem of producing high-quality steel at a low price, was solved by the invention of the Bessemer converter, whereupon steel became the fundamental construction material.[51] In addition, production engineering itself grew in efficiency as well, during the second industrial revolution. Two concepts: interchangeable parts and continuous-flow manufacturing, became essential for mechanised mass production. Interchangeability demanded high levels of accuracy and quality control but turned out very successfully for American manufacturers of, among others, firearms, sewing machines and tractors[52].

[50] See Mokyr (1998), p. 1.
[51] See Mokyr (1998), p. 2-3.
[52] See Mokyr (1998), p. 9.

### 2.4.2. *Electricity made power available where needed, resulting in more efficient factory layouts*

Once more, a new energy source played a game changing role for industrialisation. The adoption of Electricity, the key technology of the second industrial revolution, expanded rapidly after its introduction and was applied in, for instance, railroads[53]. The main benefit of electric motors compared to using water or steam as energy source was its flexibility[54]. Electricity made it possible to control the flow of energy, it could be turned on and off and adjusted to accurately match its demand. Because of its flexibility and versatility for driving machinery, electric motors replaced mechanical drives to turn the line shafts of the direct drive, without additional improvements[55]. Manufacturers were aware of the shortcomings of direct drive; The factory floor was a dangerous place to work and the shafts belts and pulleys required lots of space. Nevertheless, electricity was, in first instance, regarded as the successive method to transmit mechanical power to machine tools[56].

At the end of the nineteenth century, the consciousness that electricity could change the way how power was distributed within factories got through[57]. Owing to the transition from steam to electrical engines, power became available where needed, so factory layouts were no longer restricted by power transmission[58].Thus, manufacturing plants could be designed to let products flow logically through their subsequent operations while workers remained stationary during their activities. This production approach, called continuous-flow manufacturing, minimised wasted time between operations and led to an increase in output per worker. Ford's assembly plant developed for the Model T, for example, combined both concepts successfully in producing cars, which has had long-lasting influences for the industry ever since. Figure 2-3 illustrates the idea of continuous-flow manufacturing where electric engines (B) drive machine

[53] See Mokyr (1990), p. 6
[54] See Devine (1983), p. 364.
[55] See Devine (1983), p. 355.
[56] See Devine (1983), p. 355-357.
[57] See Devine (1983), p. 357.
[58] See Schiele (2016), p. 15.

tools (C) while unfinished goods are transported via an assembly line to the subsequent operation.

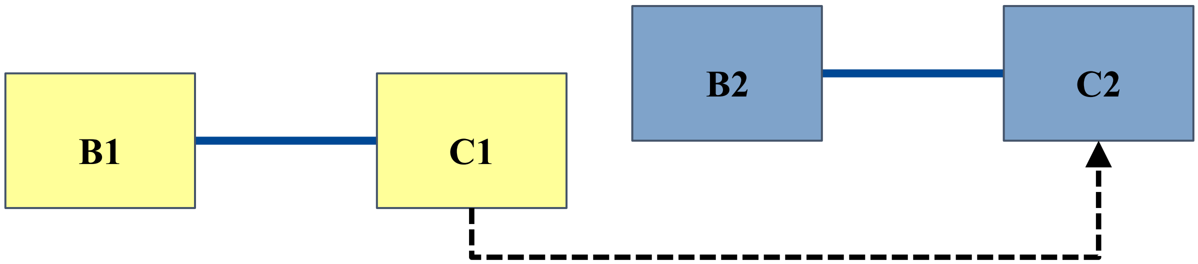


Figure 2-3 Electric unit drive with continious-flow manufacturing

### 2.4.3. *Scaling-up lead to the multidivisional organisation and scientific management*

During the second industrial revolution, the nature of organisations changed[59]. The transition to mechanisation already much improved the efficiency of production processes, but further progress was booked by optimizations in manufacturing that resulted, mostly, from consecutive incremental improvements. The benefits of economies of scale paved the way for giant corporations, such as Carnegie Steel, Dupont, General Electric, and Standard Oil[60]. Their sheer size demanded a more structural organisation as top officers were no longer able to interfere in all current affairs. To manage these large businesses effectively and to cope with diversification, the concept of the multidivisional organisation came into being.[61]

The introduction of the multidivisional structure reorganised firms based on divisions, instead of businesses as was usual back then. By adopting the multidivisional structure, board members could spend their time on long run activities while delegating short-run operational tasks to managers[62]. Separating the organisation in divisions gave corporate officers more accurate information of the performance of each business, hereby they got more grip on the course of the company. By outsourcing the daily affairs to several management layers, knowledge diffused within organisations. Most of the work in the industry was still repetitive and required a low

[59] See Mokyr (1998), p. 2.
[60] See Chandler (1992), p. 82.
[61] See Hoskisson (1993), p. 271-273.
[62] See Hoskisson (1993), p. 273.

level of education. Though, owing to the introduction of added management layers, gradually more jobs offered possibilities to influence the course of action to some degree.

The second industrial revolution is regarded as the continuation and refinement of the technological progress that started a century before. Contrary to the time of the first industrial revolution, the industry improved incrementally through consecutive enhancements. Which resulted in more efficient factory layouts and the rise of the multidivisional organisation.

## *2.5. The third industrial revolution: automation of operations in the digital age*

### 2.5.1. *Information technology increased insights in the operating results of manufacturers*

After the commissioning of electricity as a power source and the introduction of assembly lines had improved the efficiency of production, the next revolution gathered the power of electronics, information technology (IT), and robots to automate manufacturing. Unlike the first and second industrial revolution, the literature is ambiguous about the time span of the third industrial revolution. The required technological breakthrough, the first logical control system in 1969, as well as the economical need, the oil crisis of 1973 with the additional rapid increase of energy prices, are both mentioned as the catalyst of automated manufacturing[63]. Among authors there is also difference of opinion whether the third revolution has ended[64]. Some ascribe the upcoming innovations to the digitisation of production, others separate the use of electronics and IT from network connectivity adjoining manufacturing, indicating that implementing cyber-physical systems is a new revolution rather than an optimisation of automation.[65]. In general, the third industrial revolution is delimited by digitisation and automation, thus future advances (e.g. autonomous decision making) are attributed to I4.0.

Automation due to information technology amounted for increasing productivity in assembly plants paired with enhanced quality control and labour reduction. Accordingly, annual productivity growth in the manufacturing sector more than doubled in the 1980s compared to the yearly progress in the period from 1950 up to and including 1980[66]. Due to the availability

[63] See Jensen (1993), p. 836; Schlaepfer/Koch (2015), p. 3.
[64] See Rifkin (2012), p. 1-8.
[65] See Avent (2014), p. 1; Bunse et al. (2016), p. 6-7.
[66] See Jensen (1991), p. 18.

of computer power, Material requirements planning (MRP), a method for controlling a company's resources, was popularised. MRP addressed operational and financial planning and helped firms to utilise their tangible and intangible assets more effectively. Thus, digitisation led to an amplified output per operator and more insight for manufacturers in the factors influencing their operating results.

#### 2.5.2. *More autonomy for workers owing to decentralising the multidivisional organisation*

In consequence of digitisation, new industries came into being (e.g. the information, and service industry) and traditional industries changed in character[67]. For workers in traditional industries, being able to act upon information (knowledge intensive tasks) became more important than executing repetitive operations fast. So, distinctive assets in firms became less tacit and more dependent on the available information. As less knowledge remains dependent on a single person or a small group, more of it is converted systematically by the organisation, so the knowledge is easily spreadable across employees at low costs[68].

In the bureaucratic organisational style of the multidivisional firm, the higher individuals were ranked in the organisational hierarchy, the more information they possessed and the more capable they were to make decisions[69]. The conventional style of management that was successful during the second industrial revolution was characterised by concentrated power, top-down goal setting and a clear hierarchy between top management and divisions. Compared to the time of the first industrial revolution, this was already a progression towards decentralisation as divisions obtained some autonomy in decision-making and competed for financial resources[70].

However, further decentralisation towards project-based working matched better with the agility of information technology. Hereby, hierarchical organisation began operating more "horizontally", characterised by decentralised goals and where the vision emerged from teams and work groups while leaders provided general guidance[71]. ICT opened the doors for

[67] See Kapás (2008), p. 27.
[68] See Cowan/Foray (1998), p. 1.
[69] See Child/Mcgrath (2001), p. 1136.
[70] See Kapás (2008), p. 29-30.
[71] See Child/Mcgrath (2001), p. 1137.

“reengineering”, a concept that implies realising substantial improvements in organisational performance by redesigning a firm’s core business processes[72]. As ICT stimulates competition and entrepreneurship, it became evident that firms adopted a more decentralised approach to deploy specialists in market-based teams to encourage mutual competitiveness within and between teams[73]. The transition to project teams corresponds with the organisational structure “Adhocracy”, a configuration with little formalisation and distributed power, which is perfectly suited for arousing innovation[74].

In brief, the third industrial revolution further automated production with the introduction of information technology. Hereby, information and services became more important for organisations than tangible assets. The existing divisional organisational structure did not unite well the digital innovations, so working on project based approaches became more common.

### *2.6. The fourth industrial revolution: digital communication and autonomous decision-making*

#### 2.6.1. *Industry 4.0: improving competitiveness and solving global challenges simultaneously*

The current Western world faces several challenges, among which, a shrinking working population that will have to care for more elderly[75], increased competitiveness from Asian manufacturers[76], growing awareness for sustainability and its corresponding restrictions, and smart markets with an increasing demand for individualisation by consumers[77]. Industry 4.0 is presented as a contributor to solve these challenges[78]. Like its three predecessors, the fourth industrial revolution aims to solve far-reaching challenges in various domains (scientific, technological, economic, political, and social) by pursuing the latest advancements to improve manufacturing and stimulate technological growth[79]. In recent years, Industry 4.0 received much

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[72] See Attaran (2004), p. 585.
[73] See Kapás (2008), p. 30.
[74] See Mintzberg (1980), p. 336-337.
[75] See CBS, unknown author (2016).
[76] See CRS, unknown author (2015).
[77] See Glazer (1999), p. 59-60.
[78] See Kagermann et al. (2013), p. 15-17.
[79] See Hellinger/Seeger (2011), p. 27-30.

attention in the media, mainly in Germany, so the expectations are high. Hence, there are some understandable doubts whether the fourth industrial revolution will live up to its promise.

Although technology is mentioned as the driver of the fourth industrial revolution, the vision of Acatech is presumably driven more by economic motives than technology[80]. From this perspective, Industry 4.0 is a form of agenda building attempting to transfer the interests of the industry to the public agenda. Regardless of the interpretation, it is in the public interest to generate attention on how to react on the future dynamics that influence the global economy. In that respect, the engineers that created the vision of I4.0 successfully reached their goal by generating a lot of media coverage.

The key technology of Industry 4.0 is the Cyber-Physical System that integrates cybernetics, the science of automatic control systems, with physical elements[81]. Comparable to the Internet of Things (IoT), and the Internet of Services (IoS), and the Industrial Internet of Things (IIoT), I4.0 facilitates communication (via internet) to exchange information in a wide variety of applications[82]. Chapter 3 will elaborate in more detail on cyber-physical systems and machine-to-machine communication. Additionally, chapter 3 will outline the differences between I4.0, IoT and IIoT.

### 2.6.2. *Expected changes with Industry 4.0: distribution of knowledge, redistribution of roles between humans and machines, and further decentralisation of organisations*

Contrary to the focus on digitisation during the third industrial revolution, the emphasis of Industry 4.0 will probably be on communication and continuous monitoring because of two reasons. First, the exchange of information (e.g. identification, positional, environmental, historical, and descriptive data) takes place between humans, humans and machines, and between machines (M2M) in real time[83]. The expectation is that all actors in the supply chain (both humans and machines) are continuously updated with the statuses of tasks that are relevant to them at that moment. Also, the past and future diagnostics of production processes, raw materials, parts and unfinished products, goods in circulation and services, could be available

[80] See Pfeiffer (2017), p. 107-110.
[81] See Lee et al. (2015), p. 18.
[82] See Hellinger/Seeger, (2011), p. 11-13.
[83] See Cooper/James (2009), p. 320-321.

to actors at request, when this information is necessary for the actor. Second, intensive communicational interaction is expected to result in a new model of knowledge management processes, conceptualised as a community[84]. In a community setting users and machines will exchange knowledge by retrieving data automatically from the cloud, thus knowledge and communication are likely to be inextricably blended with each other. Connecting both the possession and exchange of knowledge, will mean a further step towards the distribution of knowledge in the direction of lower levels within organisations.

Especially when machines are given autonomy in making decisions, these processes are expected to require industry leaders to rethink their operations and the role and responsibilities that employees will have. The outlook for workplaces with comprehensive integration of cyber-physical systems, is that workers will fulfil the role of a strategical decision-maker. This role implies that employees can manually intervene in operations when needed, so the workforce shall be the flexible component in an autonomously organised system. Optimally, workers will be employable in a wide range of jobs to solve a variety of challenges with the aid of technological support. This approach would stimulate the creativity of workers by employing their problem-solving skills while leaving repetitive, exhausting tasks for machines. By pursuing such a distribution of roles, firms can the full potential of human-machine interaction.[85]

Further decentralisation of organisations can also be expected. As Industry 4.0 thrives on data, information needs to be accessible for employees on many different levels in organisations. Consequently, many workers will rely on data for their daily tasks. Due to the expected availability of additional knowledge on business processes for workers by adopting I4.0, it is expected that more complex tasks, that require decision making based on data, will be delegated to the operational level in the corporate hierarchy. The transformation towards more complex tasks and the need for decision making by the operational staff goes hand in hand with more responsibility. When workers need to act on information that is provided in real-time, without time for consultation with a manager, jobs on the factory floor will increasingly require more self-reliance. The organisational change towards more self-reliance can be regarded as the

[84] See Del Giudice et al. (2013), p. 275-276.
[85] See Gorecky et al. (2014), p. 289-294.

continuation and extension of project-based working, that was introduced during the third industrial revolution.

## *2.7. Is Industry 4.0 the fourth industrial revolution?*

### 2.7.1. *A revolution that was planned before it had started*

Six years ago, the German Nationally Academy of Science and Engineering (Acatech) branded the vision of how the future will look like by incorporating the internet and manufacturing, "Industry 4.0"[86]. Although there is difference of opinion whether the third industrial revolution has ended[87], the balance between demand and supply is continuously challenged. On one hand, a new set of technologies is emerging which can be deployed to improve competitiveness and customer satisfaction. On the other hand, adopting the new technologies will require substantial investments but firms will also need to review their organisational structures and business models. In this light, it is understandable that companies are careful to immerse in drastic changes. The engineers that invented Industry 4.0 foresaw that change does not happen overnight, since they regard the development as a long-term multidisciplinary project that will transform value chains and give rise to new business models[88]. Nevertheless, the development has aroused, and kept, the interest of both the industry and research[89]. Meanwhile, the industry has adopted the term globally, so the marketing of the name has proved to be effective.

Is Industry 4.0 the fourth revolution? It should be noted that fourth industrial revolution was planned before it started. Hence, all effects are projections or assumptions based on currently available insights. Nevertheless, to answer this question, a systematic approach was introduced in the beginning of this chapter. According to the systematic approach, each industrial revolution was set in motion by national or global challenges, the so-called *prologue*. Subsequently, *key technology* was introduced, aiming to solve the perceived challenges, and thereby satisfy the need. Thereafter, *organisational changes* were needed to implement the key technology in a business setting. Especially the latter is important to recognise, as the impact of technological improvements on their own is often modest.

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[86] See Kagermann et al. (2011), p. 11-14.
[87] See Rifkin (2012).
[88] See Kagermann et al. (2013), p. 19-20.
[89] See Liao et al. (2017), p. 3609.

### 2.7.2. *The coevolution of governance and technology: the successive industrial revolutions correlate with organisational structures that increasingly focus on knowledge sharing*

Moreover, it is projected that organisational changes were, and will be, needed to take advantage of the benefits. Figure 2-4 aims to visualise the coevolution of governance and technology, based on Tunzelmann's reasoning (2003)[90], by showing the four consecutive industrial revolutions and the organisational structures that were introduced during that period. Without doubt, more organisational structures were, and will be, successfully employed during the preceding three revolutions. Hence, the diagram represents a generic perspective with room for interpretation in individual cases. However, a generally observed trend from the first industrial revolution up to the third, is an increase in the distribution of knowledge from top to bottom in organisations.

Nonetheless, the transition of organisational structures from the second to the third revolution and beyond is less rigid than the transfer towards the multidivisional structure. In fact, hybrid structures with aspects of both the divisional structure and project teams are likely to be found in practice. Thus, the yellow bar in figure 2-4 indicates the ongoing influence of the multidivisional organisation.

From the moment Information Technology was introduced in the manufacturing industry, decentralisation further increased. Since IT is correlated with working environments characterised by decentralised authority, incentives that account for decreased observability, and the increased importance of knowledge workers and knowledge work[91]. Moreover, it is assumed that IT fundamentally changed the industry's character[92] since the results of Hitt et al. (1997) showed that the relationship between IT and the organisational structure did not depend on whether firms mostly employ white-, or blue-collar workers[93].

For the fourth industrial revolution, this trend of decentralisation is expected to continue. To benefit optimally from sharing knowledge in real time, firms are expected to collaborate more intensively within the organisation and with their supply chain partners. The collaboration, by

[90] See Tunzelmann (2003), p. 381-382.
[91] See Hitt/Brynjolfsson (1997), p.98.
[92] See Kápas (2008), p.27.
[93] See Hitt/Brynjolfsson (1997), p.98.

exchanging of information between project groups of different organisations, is illustrated by the three circles that are connected to each other.

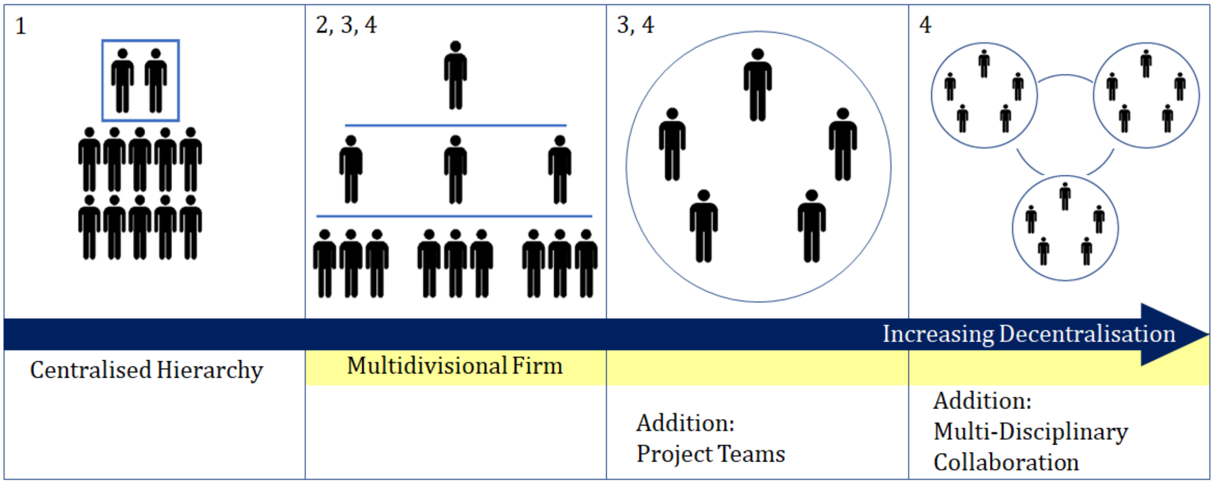


Figure 2-4 Development of organisational structures during the industrial revolutions

### 2.7.3. *Tense expectations and high stakes to make a success of industry 4.0*

As mentioned in the previous section, the fourth industrialisation addresses difficult global and national challenges, alike its three predecessors. And as the current pace of change in business is higher than ever before, being able to respond fast to the dynamics that influence large-scale challenges, is highly required by companies[94]. Having continuously updated information enables firms to act on time to maintain grip in a rapidly changing environment. In Table 2-1 this prologue is indicated as digital communication. Although this term sounds generic, it emphasises the crucial step (and distinctive for I4.0) after collecting data by continuously monitoring of processes, namely exchanging the information between humans and machines, and interpreting the data. The key technology cyber-physical systems will can provide this type of communication, after it is integrated with IT-systems.

The future will demonstrate whether Industry 4.0 will redeem its high expectations. The projections presented in this thesis followed a structural approach by analysing the prologue, key technology, and organisational changes for every revolution. The concept industrial revolution should not be taken too lightly. Flinging it about as a euphemistic buzz word would detract something from the improvements for the industry and society as whole from such

[94] See Rune By (2005), p. 378.

periods of technological breakthroughs. Thus, to stay true to the meaning of industrial revolutions, the definition used in economic historic research, was incorporated. Craft's definition of industrial revolutions, as mentioned in section 1.4, is dividable in three parts, each describing a characteristic. First, an accelerated structural change in the economy. Second, a rapid rise of industrial output and the share of manufacturing in national product. Third, a different kind of economy because of major technological innovations. The first two characteristics are unclear for now, but in the future the financial effects shall be examinable from retro perspective. The improvements of the field of response time, customisation and throughput time will probably be more substantial for supply chains, since the economy as a whole does not grow as fast as during the preceding industrial revolutions. Nevertheless, according to current insights, CPS have the potential to realise the third part because, unlike existing technology, the networking capabilities of CPS allow for real time interference with physical processes[95].

Compared to the first period of industrialisation where the transfer to mechanisation demanded a complete redesign of production processes, the extent of change perceived by the industry, is expected to be smaller for Industry 4.0. Digitisation built the foundation for the coming digital transformation, whereby companies expect to replace only 40 to 50 per cent of their currently installed manufacturing equipment[96]. Nonetheless, the transition to I4.0 will involve major changes, that require adjustments that surpass the optimising of current procedures.

### 2.7.4. *To facilitate the potential of Industry 4.0, firms need to shape their digital transformation*

Concluding, Industry 4.0 has the potential to become the next industrial revolution under the following two conditions. First, CPS and their supportive technologies involve careful implementation that requires a fresh look on the organisation of business processes. Second, extensive digital communication and monitoring are likely inevitable to make the switch to I4.0, because the benefit of physical adjustments in real-time depends on the quality of the shared information between humans, machines, and each other. Therefore, Industry 4.0 will

[95] See Lee (2008), p. 363-364.
[96] See Wee et al. (2015), p. 13-14.

presumably induce a revolution in the industry, albeit rather evolutive than disruptive, compared to its predecessors.

In the previous sections the four revolutions were described in accordance with the systematic approach. To summarise our findings, an overview of the characteristics of the four industrial revolutions is presented in Table 2-1.

Table 2-1 Overview of the four industrial revolutions
Source: Based on Tunzelmann (2003), p.371; Kapás, (2008) p. 29-30

| Industrial Revolution | First | Second | Third | Fourth |
|---|---|---|---|---|
| Estimated date | 1760 - 1820 | 1870 - 1914 | 1970 - 2000 | 2011 - Present |
| Starting location | UK | US, Germany | US, East-Asia | Germany |
| Key technology | Steam machine | Electric motors | Robots | Cyber-Physical Systems |
| Working method | Automation of labour | Continuous-flow manufacturing | Support by IT systems | Autonomic decision-making |
| Organisational change | Centralised hierarchy | Multidivisional firm | Project teams | Multi-disciplinary collaboration |

# 3. INDUSTRY 4.0: FROM DIGITISATION TO AUTONOMOUS DECISION-MAKING

## *3.1. The fourth industrial revolution: substantially increased operational effectiveness along with the development of entirely new business models, services, and products.*

The following sections discuss the literature on Industry 4.0 from its announcement until now (3.3) and the technology that enables this transformation for the industry, divided into the four components of the Internet of Things (3.4) and Cyber-Physical Systems (3.4). The aim of this chapter is to give an overview of the current research on Industry 4.0. Based on the findings of this chapter, the following chapter takes the next step by combining industry 4.0 with purchasing.

Since the shift towards outsourcing, manufacturers in upcoming nations have caught up with production facilities and drastically diminished the gap of quality and productivity between the first world countries[97]. Because of the progression of their contestants, production firms in the western world should compete on other grounds. Moreover, because of a reduction of the working age population and a decrease of industrial value in Europe, manufacturers are stimulated to adopt innovation to stay in business[98]. Technological advancements offer the industry innovative ways to stay competitive and fulfil the needs of customers, despite a decreasing working population. For example, Western industrial firms can distinguish themselves by offering consumers individualised products tailored to their needs and allowing for flexibility during the production process, while realising faster times-to-market than Asian competitors. To occupy the lead position, a change in thinking in the industry is necessary. The abilities of so-called smart and on-demand industrial manufacturing are attributes which allow leading countries, already highly developed, to outperform their competitors[99]. However, engineering in the future requires firms to deal with swift product development, flexible production as well as complex environments[100]. Thus, organisations can sustain their

[97] See Brettel et al. (2014), p. 37-43.
[98] See Qin et al. (2016), p. 173.
[99] See Neugebauer et al. (2016), p. 6.
[100] See Vyatkin et al. (2007), p. 17-18.

competitive advantage by embracing modern technologies and adopting them by reconsidering their processes.

Commenced as an initiative by the German government, aiming to secure the future of Germany's manufacturing industry[101], Industry 4.0 was officially introduced in 2011. In short, Industry 4.0 brings the internet of things to the industry and involves current technologies such as big data, advanced analytics, and human-machine interfaces[102]. The label Industry 4.0 was invented and endorsed by three German engineers: Prof. Dr. Henning Kagermann (President of the German National Academy of Science and Engineering), Prof. Dr. Wolfgang Wahlster (Scientific Director of the German Research Centre for Artificial Intelligence) and Prof. Dr. Wolf-Dieter Lukas (Head of key technologies unit at the German Federal Ministry of Education and Research)[103]. Despite of being a development initially on behalf of the German government, other countries quickly adopted Industry 4.0, among which the US, Japan, Korea, China and the UK[104].

Since its introduction in 2011, Industry 4.0 has been listed as a long-term project that involves a process in development[105]. The vision of the project depicts how the future will look like by adopting Industry 4.0 and is characterised by "a new level of socio-technical interaction between all the actors and resourced involved in manufacturing"[106]. Following the vision of Industry 4.0, tomorrow's production will occur in a "smart, networked world"[107], where the concept Internet-Of-Things has been adopted in an industrial context to carry out highly flexible and adaptable manufacturing systems[108]. Although the revolution is mainly driven by improving production for large manufacturers, changes are also expected in an organisational context, for example a transition from product- to service-orientation for SME's is expected to occur[109].

[101] See Kagermann et al. (2013), p. 5-6.
[102] See Kagermann et al. (2011), p. 5.
[103] See Kagermann et al. (2011), p. 3-4.
[104] See Kagermann et al. (2016), p. 1-3.
[105] See Kagermann et al. (2013), p. 19-22.
[106] See Kagermann et al. (2013), p. 20.
[107] See Kagermann et al. (2013), p. 19-21.
[108] See Weyer et al. (2015), p. 579-580.
[109] See Lasi et al. (2014), p. 241.

Implementing Industry 4.0 comprises a variety of technologies to enable the development of a digital and automated manufacturing environment as well as the digitisation of the value chain[110] where the central objective is fulfilling individual customer needs[111]. It integrates production facilities, warehousing systems, logistics[112], order management, R&D, commissioning and even recycling[113]; resulting in improvements in product quality and a decrease of time-to-market in addition to improvements in enterprise performance.[114]. Industry 4.0 promises substantially increased operational effectiveness along with the development of entirely new business models, services, and products.[115] Thus, to meet future demands by customers, flexible manufacturing systems might handle the need for rapid product development in complex environments[116].

Comparable to the emergence of factories during the first industrial revolution, Industry 4.0 is expected to transform plants to Smart Factories, intelligent manufacturing environments where CPS and IT are deeply integrated[117]. These Smart Factories are expected to function as nodes in small decentralised networks that act autonomously, but can be controlled from a central control room. The independent nodes, operate in response to changes of their surroundings and the company's strategic goals.[118] Due to awareness of the state of production and continuous searching for improvements, smart production is efficient for both time and resources.

According to the Industry 4.0 working group, possible benefits will also be found in a broader context. The working group lists the following opportunities: allowance for individual customer requirements, dynamic business and engineering processes, optimised decision-making, and new ways of creating value and novel business models. However, according to the working group, Industry 4.0 is also expected to solve several societal problems across the world[119]. For example, solutions to both global challenges (such as, resource and energy efficiency) and

[110] See Oesterreich/Teuteberg (2016), p. 122.
[111] See Neugebauer et al. (2016), p. 2.
[112] See Wang et al. (2015), p. 158-159.
[113] See Neugebauer et al. (2016), p. 2.
[114] See Oesterreich/Teuteberg (2016), p. 122.
[115] See Hermann et al. (2016), p. 3928.
[116] See Brettel et al. (2014), p. 37.
[117] See Wan et al. (2015), p. 135-136.
[118] See Erol et al. (2016), p. 15.
[119] See Kagermann et al. (2013), p. 5-7.

national challenges (among which, managing demographic change and promoting a better work-life balance)[120].

### *3.2. Industry 4.0 and Industrial Internet of Things are closely related but not the same, namely the use of internet is not implicit for industry 4.0 applications*

In section 1.6 our definition of Industry 4.0 was presented. However, multiple applied definitions are closely related to I4.0, but do not have the exact same meaning. Thus, to provide clarity, this section is dedicated to describing the similarities and differences within the used terminology.

#### ***Internet of Things***

The Internet of Things (IoT) is one of the major emerging trends in the IT sector and started in the last decade. The idea behind IoT is to create a network of billions of machines communicating with one another. The concept is based on three characteristics: indentification, communication, and interaction.[121]

#### ***Industrial Internet of Things***

As the name reveals already, the industrial internet of things (IIoT) entails the use of the internet of things to the industry. In March 2014 the IIoT consortium was founded by AT&T, Cisco, General Electric, IBM and Intel. The aim of the program is to transfer businesses and society by accelerating the development of IIoT. Applications of IIot are expected in a wide range of industries, among which energy, healthcare, manufacturing, public domain, and transportation.[122]

#### ***Industry 4.0***

The overall goal of IIoT and I4.0 is rather similar and comes down to supporting the competitive position of organisations for the coming years in a changing business environment, by investing in the digitisation of the industry. On the contrary, I4.0 was commenced as a government driven initiative that is mostly focused on the (German) manufacturing industry. Moreover, since I4.0

[120] See Wan et al. (2015), p. 135.
[121] See Miorandi et al. (2012), p. 1498; Buckley (2006), p. 6.
[122] See Lin et al. (2017), p. 17.

is the predecessor of the third industrial revolution instead of an extension of IoT, the use of internet is not implicit for I4.0 applications (e.g. self-filling soap distributors).

***Smart Industry***

Smart Industry is defined as follows by the Smart Industry Workgroup:

*"Smart Industries are... industries that have a high degree of flexibility in production, in terms of product needs (specifications, quality, design), volume (what is needed), timing (when it is needed), resource efficiency and cost (what is required), being able to (fine)tune to customer needs and make use of the entire supply chain for value creation. It is enabled by a network-centric approach, making use of the value of information, driven by ICT and the latest available proven manufacturing techniques."*[123]

In the Netherlands, Smart Industry is preferred over I4.0, similar to digitisation initiatives in Belgium, Denmark, the United Kingdom, France, Korea, and China, that each bear their own names even though the differences between the regional programme and I4.0 are unclear. Possibly in the future Smart Industry will distinguish itself by pursuing different focus areas, but currently Smart Industry collaborates closely with, and is dependent on, I4.0, because of the significantly larger budget disposable for I4.0.[124]

[123] Smart Industry Workgroup (2014), p. 7.
[124] Smart Industry Workgroup (2014), p. 52-53.

### *3.3. History of Industry 4.0 research: from 2011 till now*

#### 3.3.1. *The number of scientific publications on Industry 4.0 has increased exponentially in recent years*

The existing literature on the fourth industrial revolution has been growing rapidly in recent years. In 2012, the first publications on Industry 4.0 arose from Germany and Austria. Currently, Germany possesses the leading position in the field, accounting for roughly forty per cent of all publications. Other notable European countries on researching I4.0 are Spain, United Kingdom, and Austria with a cumulatively contribution to the literature of fifteen percent. Interest in the fourth industrial revolution from non-European countries increased from 2014 when journals from the United States published several articles. In 2015 researchers from China started publishing on the topic. Now, China is the second largest publishing country after Germany. Figure 3-1 offers an overview of the yearly number of publications on Industry 4.0. The graph shows an exponential growth of the number of publications and an ample doubling of the between 2013 to 2016.

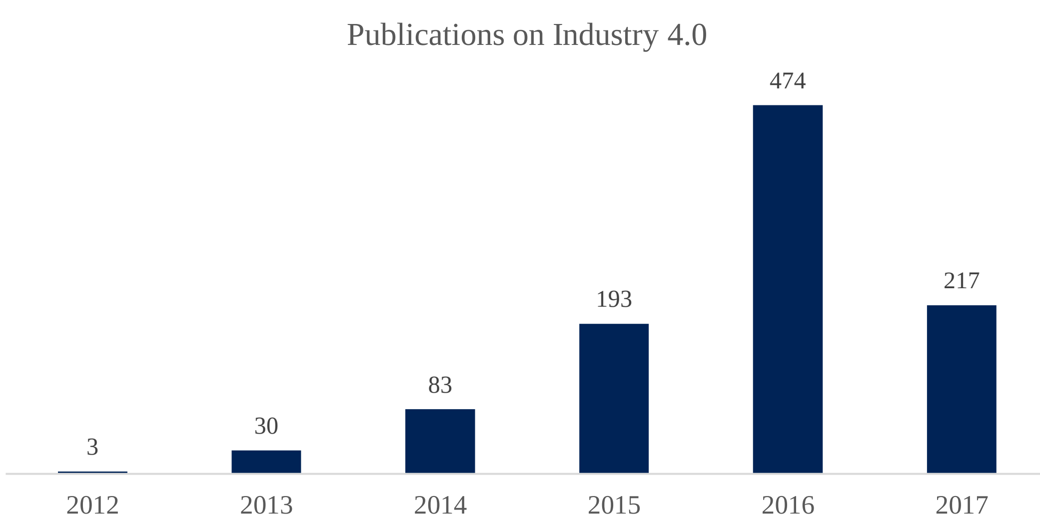


Figure 3-1 Number of publications on Industry 4.0 per year (reference date: June 18th, 2017)
Source: Scopus (2017b)

Figure 3-2 displays the trend of publications from 2009 up to 2016 found on Scopus for Industry 4.0, Smart Industry, Industrial Internet, and Cyber-Physical Systems. The percentages of the vertical axis mean the cumulative percentage of publications from 2009, so every year that articles are published, the percentage increases, up to 2016, the last year included. The slope of the lines in Figure 3-2 shows a growth rate comparable to the number of publications on Industry 4.0, as shown in Figure 3-1. Albeit the steepness of the line for Cyber-Physical Systems deviates slightly.

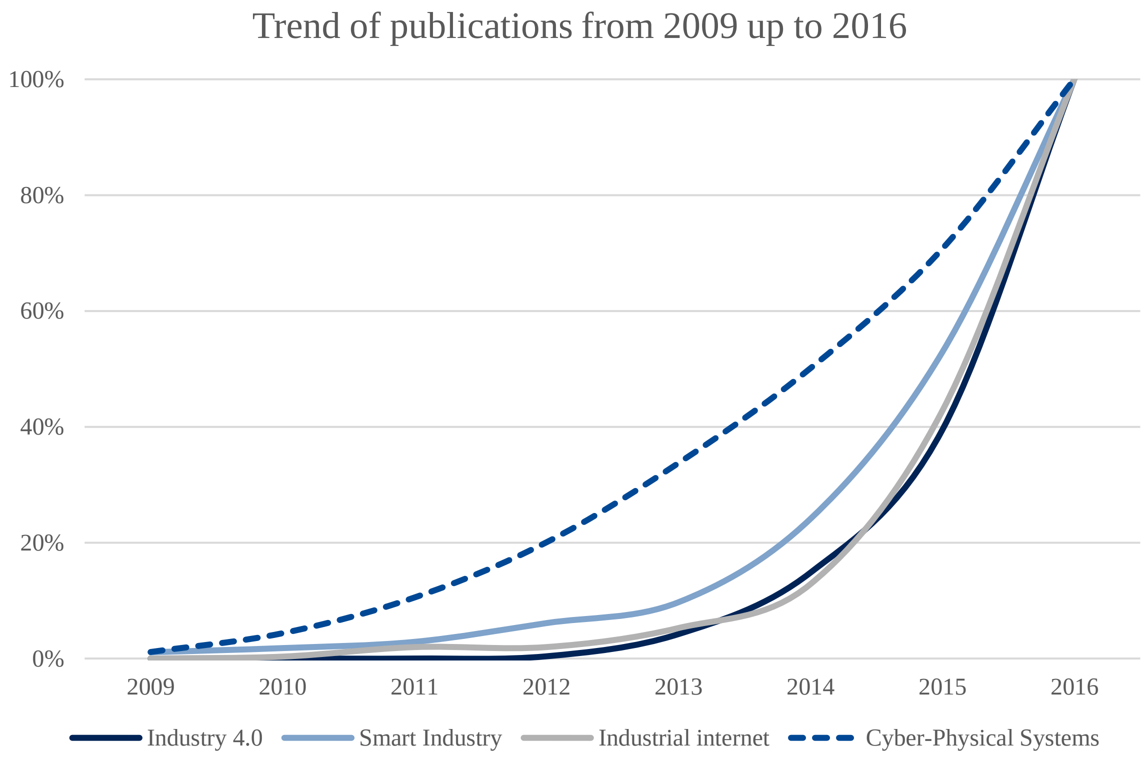


Figure 3-2 Trend of publications on Industry 4.0 and related topics (reference date: June 18th, 2017)
Source: Scopus (2017b)

### 3.3.2. *For publications in business literature, Industry 4.0 is preferred over Smart Industry, Industrial Internet or Cyber-Physical Systems*

Industry 4.0 was originally a definition that was mostly used within Germany, so, to address their audience, researchers from other countries might choose terms that share the same meaning. For example, in the Netherlands, the definition "Smart Industry" is preferred by the Dutch ministry of economic affairs to indicate the digitisation of the industrial production chain[125]. Besides Smart Industry, other frequently recurring keywords closely related to Industry 4.0 are "Industrial Internet (-of Things)" and "Cyber-Physical Systems". Table 3-1 shows the number of publications on these topics per year. Though the keywords Smart Industry and Industrial Internet have circulated for longer, the terms are present in fewer numbers. The number of publications mentioning Cyber-Physical Systems on the other hand, surpasses Industry 4.0.

Table 3-1 Yearly publications on Industry 4.0 and related topics (reference date: June 18th, 2017)
Source: Scopus (2017b)

| Year | Industry 4.0 | Smart Industry | Industrial Internet | Cyber-Physical Systems |
|---|---|---|---|---|
| 2017 | 217 | 48 | 78 | 572 |
| 2016 | 474 | 131 | 174 | 1561 |
| 2015 | 193 | 80 | 91 | 1100 |
| 2014 | 83 | 40 | 23 | 873 |
| 2013 | 30 | 10 | 10 | 729 |
| 2012 | 3 | 9 | - | 508 |
| 2011 | - | 3 | 5 | 329 |
| 2010 | - | 2 | 1 | 173 |
| 2009 | - | 3 | - | 60 |
| Total | 1000 | 326 | 382 | 5905 |

[125] See Netherlands Enterprise Agency (2017).

Although the topics, Smart Industry, Industrial Internet, and Cyber-Physical Systems are convertible terms for, or elements of, the fourth industrial revolution, publications on these three topics are found in different subject areas than Industry 4.0. In Table 3-2 a comparison is made between the subject areas of the documents found on Scopus for the four related topics. The percentages indicate that publications on Cyber-Physical Systems are found mostly in Computer Science (75 per cent), and rarely related to Business, Management and Accounting (2 per cent). Documents on Industry 4.0 are lined among, first, Engineering (67 per cent) and second, Computer Science (42 per cent). In contrast, for Industry 4.0, papers are more frequently part of the subject area Business, Management, and Accounting (19 per cent). Between related topics, the difference how publications are subdivided into subject areas indicates the relative importance of the subject areas for the respective topics. Thus, for publications on Industry 4.0, there is more interest from a business or management perspective, compared to publications on Cyber-Physical Systems, which primarily target Computer Science.

Table 3-2 Publications on Industry 4.0 and related topics by subject area (reference date: June 18th, 2017)
Source: Scopus (2017b)

| Subject Area | Industry 4.0 | Smart Industry | Industrial Internet | Cyber-Physical Systems |
|---|---|---|---|---|
| Engineering | 67% | 79% | 61% | 45% |
| Computer Science | 42% | 65% | 58% | 75% |
| Business, Management, and Accounting | 19% | 8% | 8% | 2% |
| Decision Sciences | 14% | 8% | 6% | 4% |
| Materials Science | 9% | 7% | 3% | 1% |
| Mathematics | 9% | 11% | 9% | 17% |
| Chemistry | 5% | 2% | 2% | 1% |
| Social Sciences | 5% | 2% | 4% | 4% |
| Physics and Astronomy | 5% | 4% | 6% | 3% |
| Energy | 3% | 4% | 4% | 3% |
| Other | 9% | 17% | 9% | 4% |

### 3.3.3. *Most of the literature on Industry 4.0 originates from Germany*

Table 3-3 shows the six nations with the most publications on the four topics. The results clearly indicate that the term Industry 4.0 sprouts from German origin, considering that 39 per cent of the available scientific literature originates from Germany.

Table 3-3 Number of publications on Industry 4.0 and related topics across their top five contributing countries (reference date: May 10th, 2017)
Source: Scopus (2017b)

| Industry 4.0 | | Smart Industry | | Industrial Internet | | Cyber-Physical Systems | |
|---|---|---|---|---|---|---|---|
| Germany | 39% | United States | 25% | United States | 22% | United States | 35% |
| China | 9% | South Korea | 21% | Germany | 18% | China | 17% |
| United States | 5% | China | 12% | China | 16% | Germany | 12% |
| Spain | 5% | Germany | 6% | UK | 7% | Italy | 4% |
| Austria | 4% | Japan | 6% | Finland | 6% | UK | 4% |
| Others | 38% | Others | 30% | Others | 31% | Others | 28% |

Figure 3-3 visualises a similar asymmetry of the source of the literature on the fourth industrial revolution where the intensity of the colour blue indicates the number of publications. The picture clearly shows the leadership of Germany in the field.

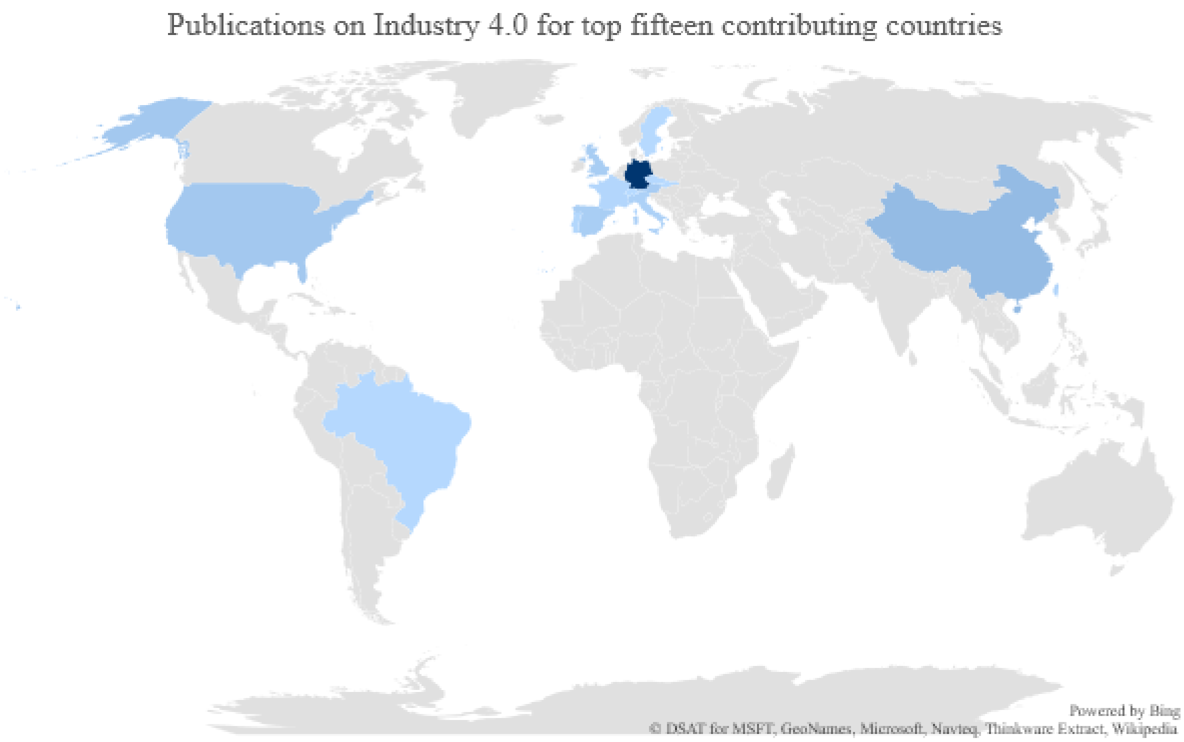


Figure 3-3 The total number of publications on Industry 4.0 per country (reference date: June 18th, 2017)
Source: Scopus (2017b)

### *3.4. Key topics of Industry 4.0 in scientific literature*

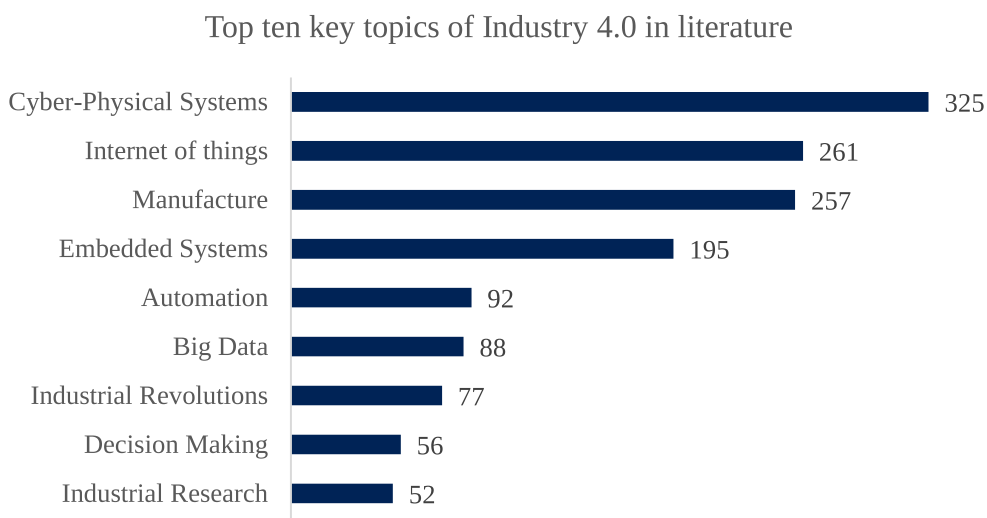


Figure 3-4 Key topics of Industry 4.0 in literature (reference date: August 18th, 2017)
Source: Scopus (2017b)

The ten most named topics in the literature on Industry 4.0, in order of total number of mentions, are: Industry 4.0 (1) This result is excluded in the figure, since it was the query term; Cyber-Physical Systems (2); Internet of Things (3); Manufacture (4); Embedded Systems (5); Automation (6); Big Data (7); Industrial Revolutions (8); Decision Making (9); and Industrial Research (10). Figure 3-4 shows how often each key topic is mentioned as subject in scientific publications from a total of 1,168 results. Synonyms, abbreviations, and different spelling of the same topic (e.g. CPS, Cyber-Physical, Cyber-Physical System) were added up.

Starting, a concise explanation of Embedded Systems and Big Data, to provide clarity since these concepts are sometimes explained ambiguously in the literature. Thereafter, section (3.4) and (3.5) will elaborate on the topics Internet of things and CPS. Section (3.6) closes with possible scenarios of implementing Cyber-Physical systems in production.

### 3.5. *Industry 4.0's constitutional technologies: Machine-to-Machine communication and Cyber-Physical Systems*

#### 3.5.1. *Big Data and Embedded Systems: supportive technologies preceding Cyber-Physical Systems*

In recent years CPS generated much attention, but what preceded this development? This section explains which components laid the foundation for the emerging technology that aims to join the virtual and physical world together. The goal is to provide basic insights in the functionality of the components and how they differentiate from each other, without diving into technical details, as the former is more relevant from a business perspective.

First, as discussed earlier in this report, a concise explanation of two supporting technologies of Industry 4.0: Big Data and Embedded Systems. Big Data refers to extremely large datasets that due to their size cannot be moved for analysis[126]. The exponential growth of generated data and the ability to analyse and interpret this information, offers a positive outlook for both research and business. However, the ability to collect heaps of data might result in a paradox of choice, when there is too much information to process. In that scenario, decisions in real-time should be made whether to maintain or delete data. Several definitions of Big Data exist, diverging from expressing the technology behind Big Data to its impact in practice. The following definition of Big Data by is used in this research: *"Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value.[127]"*

Embedded Systems combine computing and physical tasks in a device of which the software is shielded from the user[128]. Unlike personal computers that are universally deployable for a wide range of tasks, embedded systems favour specialism. Embedded systems are engineered to perform simple tasks in specific scenarios (e.g. a digital calculator). The resources of these small computers are limited to fit their tasks just right, which makes them affordable. However, the greater benefit of the narrow application of these systems, is their reliability (e.g. for

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[126] See Alexander et al. (2011), p. 10-11.
[127] See De Mauro et al. (2015), p. 103.
[128] See Lee (2006), p. 3.

pacemakers).[129] CPS are also embedded systems, albeit more sophisticated, and will thus meet familiar considerations with respect to affordability and reliability.

### 3.5.2. *The four components of the internet-of-things: Radio Frequency Identification, Wireless Sensor Networks, Machine-to-Machine communication and Cyber-Physical Systems*

The rise of the internet has had a big influence on how people interact with each other in a professional setting and beyond. By means of the internet-of-things (IoT), digital communication is extended to devices, sensors and chips that are connected to the internet, so-called smart objects that can describe the possible interactions with their environment[130]. The term IoT was first introduced in 1999 and continues to be a hot topic in the IT world[131]. IoT is applicable as an umbrella term for all technologies that detect and communicate information and are heterogeneously accessible, including radio frequency identification (RFID) chips, Wireless Sensor Network (WSN), Machine-to-Machine communication (M2M) and Cyber-Physical Systems (CPS)[132]. The three fundamentals of IoT are: first, hardware to sense and communicate information. Second, devices to store and analyse data. Third, visualisation tools that extract meaningful information from data, essential for decision making.

RFID chips are the most basic IoT components, generally, this technology is used to store and communicate information by placing a tag on individual products or shipments. The chip holds all relevant data and can be read with use of a reader, that can track the physical movements of the tag. RFID chips are cost-effective and thus widely applicable in many use scenarios, ranging from inventory management to loss-resistant golf balls. Two variants of RFID tags exist, active and passive chips, of which passive chips are the cheapest, with a price of around ten cents apiece.[133]

WSN is a set of sensors that autonomously monitor physical or environmental conditions. Then the recorded data is sent through the network to a main location[134]. The sensors are distributed

[129] See Harris (2017).
[130] See Kallmann/Thalmann (1999), p. 74.
[131] See Madakam et al. (2015), p. 165-166.
[132] See Chen et al. (2004), p. 481-482.
[133] See Zhu et al. (2012), p. 152-154.
[134] See Chen et al. (2004), p. 482.

over different process steps and work together to create an overview of the recorded information. When WSN are deployed together with RFID, information regarding the presence and location of objects can be merged with the status of their environment, thereby generating a more profound report[135]. Moreover, the reading range becomes much larger when RFID are supported by WSN, which increases the employability. However, as passive RFID tags have quite low ranges (up to ninety centimetres)[136], and RFID readers are still quite expensive, applications in practice are likely to be found in situations where readers can be attached to robots, cars or a person's hands[137]. When the two technologies can be combined in a cost-effective manner, promising results for supply chain partners can be expected, particularly for complicated products with many components and replaceable parts, such as cars.

M2M entails connectivity among computers, smart sensors, embedded systems and their peers, without or with limited human intervention[138]. RFID and WSN support M2M by delivering the recorded information from sensors, subsequently the data is transmitted autonomously. The added value of M2M for the industry resides on two benefits[139]. First, a machine connected to a network is preferred over a stand-alone machine, because the former can easily share diagnostics. Second, multiple connected machines create opportunities for autonomously coping with variability. Currently, many standards exist for M2M with different typical applications. For the adoption in the long term of M2M, it expected to be crucial to develop universally accepted standards to ensure compatibility across different industries[140]. Currently, M2M is the most common form of IoT in the industry[141].

In recent years an evolution of M2M has emerged with the introduction of CPS. The following section will take a closer look at this technology, but its main characteristics are addressed below. CPS is a variant of M2M with the added capabilities of decision making and autonomous control and is thus more complex. The development of CPS is aimed at the development of cross

[135] See Jain/Vijaygopalan (2010), p. 1.
[136] See Roberti (2013).
[137] See Liu et al. (2008), p. 31-32.
[138] See Watson et al. (2004), p. 1.
[139] See Wan et al. (2013), p. 1106.
[140] See Chen et al. (2012), p. 484-486.
[141] See Chen, et al. (2012), p. 482.

domain intelligence and the interaction between the virtual and the physical world[142]. Further, CPS emphasise on real-time control and high degrees of automation.

Figure 3-5 shows the coherence between the four components of IoT that were treated in this section.

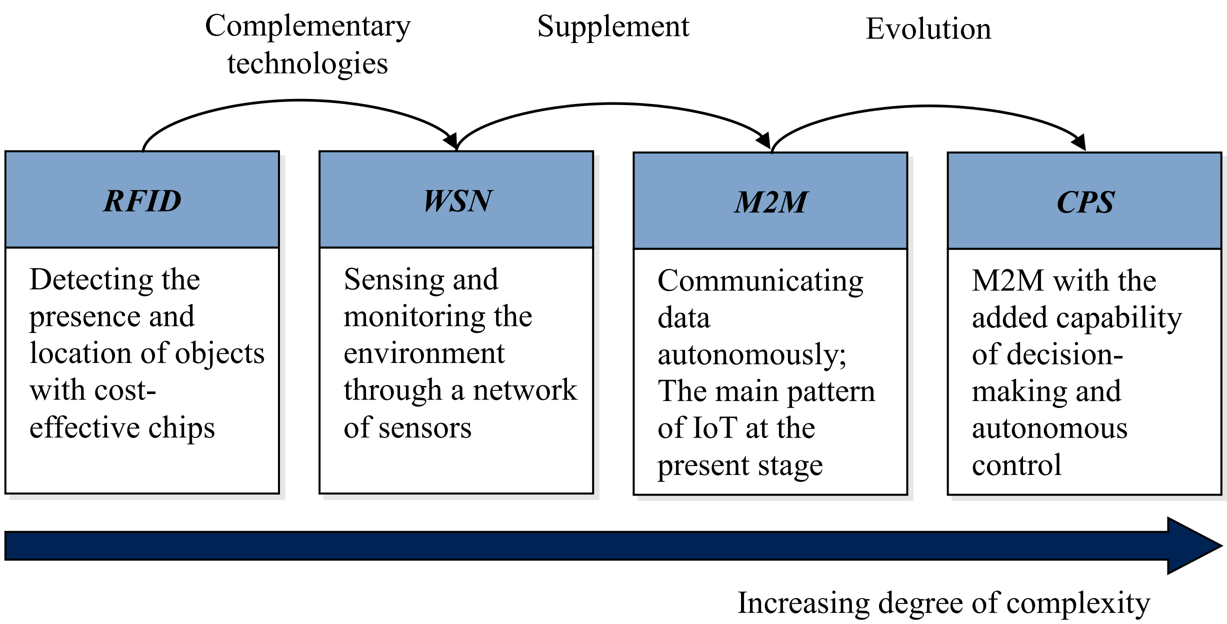


Figure 3-5 Components of Internet of Things

Furthermore, as opposed to the perceived and expected benefits of IoT, there will also be difficulties. A clear example of a practical limiting factor for the extensive adoption of IoT is the existing structure of how the internet is used today[143]. Currently, the internet is based on host-to-host communications, which implies that during a conversation, both the sender and receiver of information have a unique identifiable address. Every device with an active internet connection has its own IP address, but the number of available addresses is not endless, so this restriction could hinder the growth and total number of IoT devices. As the main use of the internet is publishing and retrieving information, the internet of the future could be restructured with the focus on information and communication itself, regardless of the sender and receiver of the information[144].

[142] See Wan et al. (20130, p. 194.
[143] See Atzori et al. (2010), p. 2803.
[144] See Atzori et al. (2010), p. 2803.

### *3.6. Cyber-Physical systems adjoin cyberspace with the physical world*

Continuous advancements in information technology has enabled chips to grow exponentially in computing power yet shrink in size and increase in affordability[145]. The five decades succeeding Moore's law, as already predicted in the mid-sixties, led to many new use cases of computers, among which, home computers, self-driving cars and smartphones[146]. Now is the golden age of digital innovation, because mobile technology can collect data and transfer information via cloud computing affordably for mass-production, which will challenge the manufacturing industry and thus requires the interest of scholars in management sciences.[147] Compact, yet powerful devices, housing a variety of sensors with built-in functionality to share information via the internet, will alter the interplay between humans and the physical world similarly to the transformation of human interaction because of the internet.[148]. As mentioned earlier, CPS are the driving force behind the fourth industrial revolution and are expected to bring breakthroughs as revolutionary as the introduction of mechanical looms, assembly lines and programmable logic controllers[149].

Tendencies in manufacturing suggest organisations to achieve a stronger competitive position, by utilising advanced analytics and CPS to make their operations more efficient and increasingly productive[150]. A key point to benefit from Big Data is transparency, the ability of manufacturers to distil valuable information about their operations to gain objective insights of the organisation's capabilities and possible uncertainties[151]. Thus, to achieve more transparency, systematically handling information by examining and integrating process data arises is becoming increasingly important for the industry.

From an inter-disciplinary view on science and technology, CPS integrate the cyberspace with the physical world[152] by adjoining knowledge on software and hardware, two research fields distinguished from each other by different methodologies[153]. Currently, use cases for

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[145] See Nordhaus (2001), p. 38.
[146] See Moore (1965), p. 82.
[147] See Fichman et al. (2014), p. 349.
[148] See Rajkumar et al. (2010), p. 731-732.
[149] See Monostori (2014), p. 11.
[150] See Lee et al. (2013), p. 39.
[151] See Lee et al. (2013), p. 39; Lee/Lapira (2013), p. 6.
[152] See Wan et al. (2011), p. 1892.
[153] See Horváth/Gerritsen (2012), p. 20.

implementing CPS are investigated in various sectors, among which, continuous patient monitoring in the medical device industry[154], collaboration between humans and robots in assembly[155] and smart cities, housing many sensors which collectively gather data whereupon physical actuators can act[156]. Acatech distinguishes the following scenarios for implementing CPS[157]: Smart Mobility, Smart Health, Smart Grid, and Smart Factory.

Although all four scenarios are interesting for further research, the scope of this paper is limited to implementing CPS in supply and production, elements of smart factory.

Within an interdependent manufacturing supply chain consisting of suppliers, manufactures and customers, a cyber-physical production network can be used to share information with all involved parties in real time[158]. Shared information can, for example, be communication or negotiation with suppliers or sharing configurations for products. Crucial, yet underexposed, in sharing of information via a network of CPS, is the presence of a 'single source of truth' through a common database to avoid ambiguity[159].

Potential scenarios for using CPS in manufacturing include: similarity identification by comparing peers (subsequent identical products) during the production process to assure consistent quality of production[160]; degradation monitoring and predicting remaining useful life of components to[161]; saving digital product memories, similar to keeping a diary, of all relevant events during the complete life cycle of a product for further analysis[162] Currently, CPS are already employed in practice, but mostly in enclosed areas without possibilities for interaction outside the borders (e.g. the usage of automated guided vehicles at Hamburg's container terminals)[163].

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[154] See Lee/Sokolsky (2010), p. 743.
[155] See Wang et al. (2015), p. 517-520.
[156] See Zanni (2015), p. 1-3.
[157] See Geisberger/Broy (2012), p. 29.
[158] See Lasi et al. (2014), p. 240-241.
[159] See Eigner/Fehrenz (2011), p.403-404; Schuh et al. (2014), p. 52.
[160] See Lee et al. (2015), p. 20-21.
[161] See Lee et al. (2015), p. 19.
[162] See Brandherm/Kröner (2011), p. 374.
[163] See Briskorn et al. (2006), p. 611-613.

# 4. PURCHASING SUPPORTING INDUSTRY 4.0: INTEGRATING DATA ACROSS VALUE CHAINS

## *4.1. The procurement function: from an administrative role to a strategic element of the organisation*

This chapter starts with a brief history of the development of the role of purchasing, recommendations and expected future trends in the field of purchasing in section 4.1. Subsequently, section 4.2 continues with an analysis of current gaps in the literature of Industry 4.0 that are interesting for procurement. On grounds of the discovered gaps, an agenda for future research is outlined.

Up till and well into the 1970s procurement was primarily viewed as a passive function by top management[164]. However, in the 1980s, after long neglect by organisations, research produced new insights, including closer collaboration between the purchasing staff and design engineers[165]. In addition, the strategic power of suppliers and buyers was expressed and in consequence, the strategic importance of purchasing started increasing[166]. The attention for purchasing and its strategic role to improve the firm's competitive advantage continued to grow in the decades that followed[167]. In the 1990s ERP systems were introduced, which encapsulated operational activities and their corresponding accounting activities[168]. ERP systems centralised the insights of many processes (e.g. financial management, demand forecasting, production planning and purchasing) in a comprehensive overview. By gathering all relevant information in a single location, managers increased their understanding of the current state of business processes and could intervene faster than before.

In the beginning of the 2000s, procurement systems started embracing the new possibilities that the internet offered. Online purchasing systems (e-procurement) have been developed to conduct procurement and sales flows via the internet[169]. At first, e-procurement initiatives had difficulties getting off the ground. The digitisation of purchasing faced the following three

[164] See Ellram/Carr (1994), p. 11.
[165] See Burt/Soukup (1985), p. 10.
[166] See Porter (1979), p. 140-142.
[167] See Ellram/Carr (1994), p. 11.
[168] See Jacobs/Weston (2007), p. 361.
[169] See Davila et al. (2003), p. 11.

difficulties: inconclusive standardisation, incomplete e-procurement-based services, and maverick buying together with problems concerning integration with existing systems[170]. To cope with these challenges, research recommends three best practices. First, any improvement to existing business processes is best implemented before subsequent steps are taken, because new technologies cannot heal ineffectively designed processes. Second, adoption by users must be central to gain the support of employees and to prevent undesired behaviour, such as maverick buying. Third, all stakeholders should be involved. Collecting their input increases the speed to renew business processes.[171] Challenges of the same nature can be expected when the next iteration of the purchasing processes arises. Thus, to make a success of future progressions in purchasing, recommendations of the past are helpful to face challenges.

Findings from a literature review on purchasing by Zheng et al. (2007) indicate that the nature of the business environment with regards to outsourcing, achieving sustainability goals and increased attention for maintaining long term relationships with suppliers has impacted the strategic role of purchasing[172]. The expansion of the role of purchasing towards more engagement, compared to its former clerical role, is emphasised by the broad set of competences with added emphasis on 'soft' skills that are required by purchasing professionals nowadays.

Future expectations are the continuation of the increasing importance for collaboration between buyers and suppliers[173] and the disappearance of the lone commodity buyer in favour of cross-functional and cross-enterprise teams that make purchasing decisions together in consultation[174]. The expected shift towards cooperation and more attention for strategic partnerships underlines the need for good communication of information. The technologies of I4.0, aimed at collecting data and facilitating digital communication, are the means par excellence to support the expected developments of procurement. Since the integration of purchasing and I4.0 is in a pre-mature phase, experiments are likely needed to test its added value in practice.

Figure 4-1 illustrates the operational relief and strategic influence of digital support systems from Material Requirements Planning (MRP), via Enterprise Resource planning (ERP), and

[170] See Angeles/Nath, (2007), p.112-113.
[171] See Aberdeen Group (2005), p. 7.
[172] See Zheng et al. (2007), p. 77.
[173] See McIvor et al. (1997), p. 167-174.
[174] See Zheng et al. (2007), p. 78.

eProcurement, to Purchasing 4.0. The graph indicates the logical flow from basic tools that were used in the 1970s to increasingly comprehensive support systems that are expected in the near future.

At this point in time, the boundaries of purchasing 4.0 are not yet defined, so it is uncertain what shall be considered purchasing 4.0 in the long term. According to figure 4-1, Purchasing 4.0 will have the highest strategic influence and operational integration in relation to foregoing developments in purchasing. Thus, the next section continues by describing various research gaps to investigate the potential of I4.0 for purchasing in a broad sense.

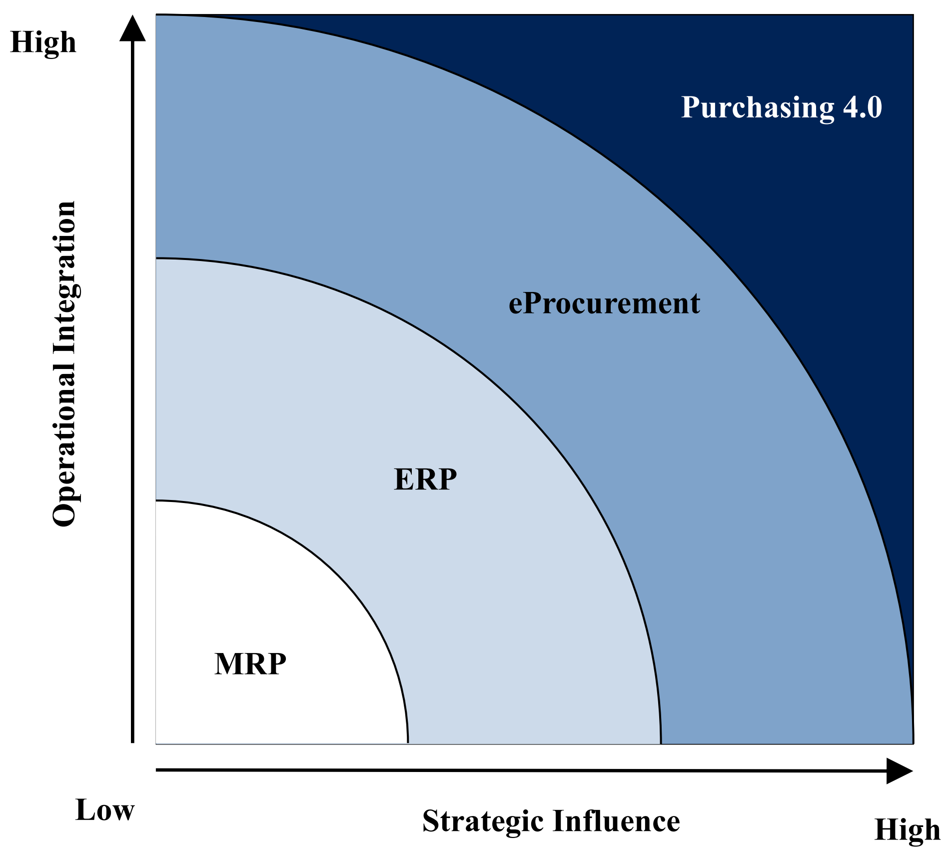


Figure 4-1 Development phases towards the digitisation of purchasing
Source: Based on Kleemann et al. (2017), p.11

### *4.2. Purchasing with Industry 4.0: future research on based on current findings.*

#### 4.2.1. *Overall research directions for purchasing with industry 4.0: expected general challenges, tailored roadmaps, and projected developments on a higher level*

From the literature analysis that was conducted in chapter three, follows that two highly cited articles, relative to other articles in the field, give general directions for further research. First, the article by Lee et al. (2015) introduces an architecture of five levels with increasing complexity as a step-by-step guideline for the implementation of Cyber-Physical systems[175]. Their architecture is aimed at manufacturing, but the general direction of the proposed structure is applicable to business research as well, albeit in a revised form. According to this logic, the accompanying attributes per level could serve as directions for future research in the field of purchasing. Second, the paper by Monostori (2014) closes with an outline of R&D challenges that are applicable to a broad range of research fields, which are related to cyber-physical systems in production[176]. A third often cited document, although not indexed by Scopus, that provides directions for further research, is the extensive report from the "Industrie 4.0 Working Group" by Kagermann et al. (2013)[177]. The contribution of these three mentioned articles is that they give researchers at least some guidance by appointing generic research directions and expected challenges.

On the contrary, also papers that contribute more specific research directions are available. Gubbi et al. (2011), for example, has included a roadmap for Internet-of-Things applications across various domains during the timespan from 2010 to 2025 and beyond[178]. The three main research directions in big data technologies and the new manufacturing paradigms derived therefrom, are mapped by Esmaeilian et al. (2016)[179]. Their structure for the shift from data collection to data analytics and decision making and the implications for manufacturing thereof, provides guidance for new purchasing paradigms based upon the same three research directions in big data technologies.

[175] See Lee et al. (2015), p. 19.
[176] See Monostori (2014), p. 12.
[177] See Kagermann et al. (2013), p. 6-7.
[178] See Gubbi et al. (2013), p. 1656.
[179] See Esmaeilian et al. (2016), p. 91.

The foregoing research directions supplemented with expected developments of I4.0 on global and national levels as described by Kang et al. (2016)[180], the expected future directions of purchasing according to the key findings of the most recent purchasing literature review by Zheng et al. (2007)[181], and the main research directions of I4.0 pointed out by Liao et al. (2017)[182], serve as the foundation for the development of a research agenda for purchasing 4.0.

#### 4.2.2. *Main contributions from the most cited publications on Industry 4.0: required characteristics for practical applications and a guideline for the development of Cyber-Physical Systems*

According to Kagermann et al. (2013) implementations of I4.0 must satisfy three characteristics[183]:

- *Horizontal integration:* the aggregation of distinct supportive IT systems through value networks (suppliers of raw material, manufacturers, etc).
- *Vertical integration*: the integration of support IT systems used at different hierarchical levels (e.g. the sharing of data and acting upon this information during the successive stages of the manufacturing process).

The overarching aim of both horizontal and vertical integration is to achieve end-to-end digital integration.

- *End*-to-*End digital integration:* the integration of all functions across the entire value chain, from product design and development to production and services. End-to-end digital integration is the most difficult aspect to achieve, as it encompasses collaboration by mutually sharing digital information within and outside the firm. By adjusting the operations to create win-win situations for the supply chain partners, the goal of an interlinked supply chain would be achieved. Possibilities on how to deploy supply chain control towers could be further researched. The concept relies on using artificial intelligence for data analysis to bring people, processes and together, and resembles an

[180] See Kang et al. (2016), p. 123-124.
[181] See Zheng et al. (2007), p. 76-77.
[182] See Liao et al. (2017), p. 3620-3622.
[183] See Kagermann et al. (2013), p. 6.

interesting research direction to approach digitally interlinked supply chains[184]. Currently, IBM is engaged in supply chain control towers and many websites mention the term, but the topic seems underexposed in scientific research. For the future of purchasing with I4.0, more research on the applications of artificial intelligence to data analysis could be used, among others, for intelligent market analytics, better prognostics of supply and demand and learning, and self-learning purchasing systems for automatic purchasing.

The three before mentioned characteristics (horizontal integration, vertical integration, and end-to-end integration) are largely practice oriented. In contrary, the five-layer architecture (see Figure 4-2) by Lee et al. (2015) presents a more abstract guideline on how implementations of CPS are expected to develop. However, the added value of the architecture is two-fold. First, it provides a structured plan on which steps to take first and thereby the model puts the progression in a logical order. Second, their paper is written from a computer science perspective, so it emphasises clearly what is, and will become, technologically possible without any philosophical extensions on what might happen.

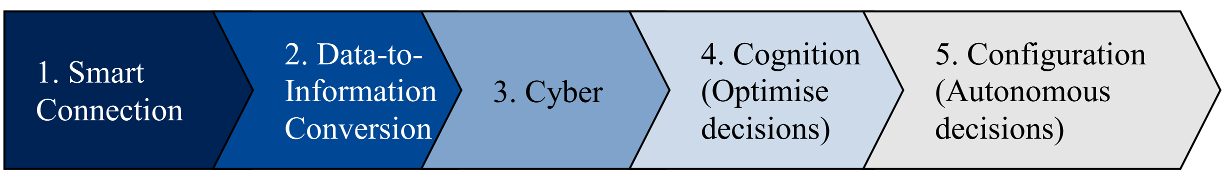


Figure 4-2 Five-layer architecture for the implementation of Cyber-Physical Systems

Source: Based on Lee et al. (2015), p. 19.

The first, most simple, layer "smart connection" is about condition monitoring. Applications for purchasing could be continuous monitoring of supply and demand, real-time market analytics, the inclusion of services with products by collecting data provided customer usage. The challenge is to research which data can be collected and how this data can generate added value. For example, data might be measured by sensors or forwarded by a digital support system (e.g. ERP or an eProcurement system).

The second layer goes one step further by converting data to meaning full information. In this respect, one may think of (at least partially) autonomous systems for operative procurement that

[184] See FocusingFuture, unknown author (n.d.).

can automatically place orders based on prognostics. Another opportunity is how extract the right information on time from using Big Data analytics.

The third layer combines the real world with the digital world. The possibilities for a fusion of real and virtual systems to expand autonomous systems for automatic ordering, could be further investigated. As well, as the human-machine symbiosis; how can purchasers seamlessly cooperate with supportive technologies in a digital world?

The fourth layer highlights the need to prioritise and optimise decisions. Research on how to develop and adopt a reference architecture for a decision support system with the aim of automating the supplier selection process would be useful here.

The fifth layer is the hardest to reach as it presumes the level of autonomy from systems to find actions to avoid. Cooperative purchasing systems are expected to able to learn from input generated during design, production, usage and perhaps even waste processing. In an interlinked supply chain, this would fully utilise the possibilities of I4.0, since the specification phase of strategic purchasing is affected by feedback loops during all later stages. However, realising a cooperative purchasing system will require much effort from many parties and the added value of such a complex system might not counterbalance the required efforts.

### 4.2.3. *Purchasing with Industry 4.0: an agenda for future research based on current challenges*

Building on a further conceptualization of the definition presented in section 1.6 and a more extensive literature review in chapter 3 and 4, we define the following I4.0 topics for the purchasing literature.

***The use, and inclusion of Big Data, cloud analytics, and data modelling to increase the efficiency of purchasing.***

In 2013, the Boston Consulting Group estimated the total spending on Big Data at 34 Billion dollars[185]. Making use of data analytics to make faster, better decisions, appears promising, but how can organisations extract value from mountains of information? From a literature review of Big Data Analytics (BDA) for supply chain management several future research directions

[185] See Brock et al. (2013), p. 1.

were derived. Among which, the impact of BDA on the organisational level and the supply chain level when these technologies are used only in a localised portion of the supply chain[186]. To which level of detail does collecting lots of data add value; should there be boundaries of data collection to maintain a clear overview of processes? Who owns the data?

***Deploying machine-to-machine communication and cyber-physical system to minimise inventory costs, and/or, eliminate stock in supply chains.***

Deploying machine-to-machine communication and cyber-physical system to minimise inventory costs, and/or, eliminate stock in supply chains. How can real time information, advanced analytics, and data driven production be aligned to produce the requested products at the right time against competitive costs (compared to current production systems)?

***The impact of the development of organisational structures, resulting from the four industrial revolutions, on organisational efficiency.***

From the second industrial revolution scientists and consultants let the sharing of knowledge within the organisation and beyond, appear inevitable for a successful transition to Industry 4.0[187]. However, in practice, organisations show resistance and hesitation to come along with the suggestions by experts. How much transparency is genuinely needed in firms, to adopt I4.0 effectively?

***Real-time assessment of competing proposals.***

Manually assessing proposals is a time-consuming process. Thus, it is worthwhile to investigate how this task could be delegated to decision support systems. Auditing is expected to transform from manually collecting data to managing a network of decision support systems. Obtaining relevant information from databases can start via data mining, text mining, and gradually advance to continuous monitoring. [188]

[186] See Wamba/Akter (2015), p. 65.
[187] See Kagermann et al. (2013), p. 49.; Reinhard, et al. (2016), p. 32. as well as Wee et al. (2015), p.21.
[188] See Hunton/Rose (2010), p. 307-309.

***Quantitative supplier evaluation and supply chain efficiency, regarding Industry 4.0 practices.***

According to a literature review on supplier selection and evaluation, containing 78 articles from 2000 to 2008, the most popular approach in supplier selection is Data Envelopment Analysis[189]. In supply chain management, evaluation techniques are used to design, manage and coordinate streams of materials/products, information and financial flows with the aim of increasing the supply chain's profitability[190]. In recent years, Data Envelopment Analysis has become the most influential mathematical tool with a wide range of applications to test assumptions about performance, productivity, and efficiency[191]. Due to its versatility, Data Envelopment Analysis could be used in supply chains to quantitatively evaluate the impact of I4.0 practices of suppliers and consequently accelerate the adoption of I4.0 within the supply chain.

***Digital, autonomous negotiation through artificially intelligent avatars.***

There have been programmes for digital negotiations, but the software used was too much focused on receiving the lowest price. Thus, there was little incentive for sellers to participate[192]. Now, the technology is ready to try digital negotiations again, this time with artificial intelligence (AI). Chohra et al. (2008) provide an example of how negotiation behaviours, with different strategies, can be simulated by artificial intelligence[193]. Since decisions made by AI improve over time, pilots should start with non-critical items. A longitudinal study, perhaps in a simulated environment, could be used to compare the results of human negotiations with negotiations through avatars.

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[189] See Ho et al. (2010), p. 21.
[190] See Soheilirad et al. (2017), p. 1.
[191] See Cook et al. (2014), p. 4.
[192] See Wise/Morrison (2000), p. 2-4.
[193] See Chohra et al. (2008), p. 127-132.

# 5. A MATURITY MODEL TO SUPPORT THE PURCHASING FUNCTION OF ORGANISATIONS

## *5.1. Maturity models: tools to identify the current state of development and provide guidance for systematic improvement*

This chapter explains what a maturity model is and introduces the existing maturity models for purchasing with I4.0. Thereafter, in section 5.2, an ideal world scenario is sketched to give an impression how the future of purchasing might look like with the adoption of I4.0 technologies.

In the literature, there appears no universally accepted definition of what a maturity model is[194]. In general, a maturity model is a tool used to identify the level of sophistication and the status of current practices for specific organisational areas. The tool is embedded in a matrix with many questions subdivided per category. During semi-formal interviews, these questions form the basis for a discussion about the current state of practices to determine in which stage the organisation is.

The work by Gibson and Nolan (1974) is considered as the foundation of the concept of maturity model of four stages[195]. Their maturity model was used to identify the stage of growth of the Electronic Data Processing department and gave management a course of action in each stage[196]. Maturity models are helpful tools to assess the situation as-is and provide guidance to management for systematic improvement[197], following a logical evolution path of a sequence of maturity levels[198]. The maturity levels are comparable to the growth of living organisms since the stages are successive, difficult to reverse and relate to extensive changes in a wide spectrum of the organisation[199].

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[194] See Bititci et al. (2014), p. 3065.
[195] See Bititci et al. (2014), p. 3063.
[196] See Gibson/Nolan (1974), p. 76-77.
[197] See Iversen et al. (1999), p. 67.
[198] See Becker et al. (2009), p. 213.
[199] See Gottschalk (2009), p. 77.

In advance, the need of developing a new maturity model, should be verified by examining existing models[200], because sometimes old models can serve as the foundation to build the new model upon, by using the current level of knowledge effectively [201].

## 5.2. Currently several maturity models for industry 4.0 exist

### 5.2.1. Overview of current maturity models to assess industry 4.0 readiness

Several maturity models have been published to assess the state of adoption of I4.0 practices in organisations, as orderly represented by Schumacher et al. (2016). Some of these tools are presented as readiness models. The label readiness indicates that the tool aims to capture a starting point for further development from an initial setup before the maturity process has started. Nevertheless, the intent of maturity and readiness models is alike since both tools present a guideline for systematic progress.[202] Table 5-1 offers an overview of existing maturity models for I4.0. Thereafter, some models shall be shortly explained. Mapping and comparing several existing maturity models helps to combine different points of view before building a new maturity model.

[200] See Becker et al. (2009), p. 214.
[201] See Zelewski (2007), p. 96-98.
[202] See Schumacher et al. (2016), p. 162-163.

Table 5-1 Existing Industry 4.0 readiness and maturity models
Source: Based on Schumacher et al. (2016), p. 162-163.

| Model Name | Year | Institution/ Source |
|---|---|---|
| The Connected Enterprise Maturity Model | 2014 | Rockwell Automation[203] |
| IMPULS – Industrie 4.0 Readiness | 2015 | Institut der deutschen Wirtsschaft Köln consult, RWTH Aachen, VDMA[204] |
| Empowered and Implementation Stratey for Industry 4.0 | 2016 | Lanza et al.[205] |
| Industry 4.0/ Digital Operations Self-Assessment | 2016 | PricewaterhouseCoopers[206] |
| Reifegradmodell Industrie 4.0 | 2016 | Jodlbauer et al.[207] |
| System Integration Maturity Model Industry 4.0 | 2017 | Leyh et al.[208] |
| Reifegradmodell: 4.0-Readiness | 2017 | Kleemann/Glas[209] |

### 5.2.2. *Industrie 4.0 Readiness model*

The readiness model "Industrie 4.0 Readiness" is developed in cooperation by two research institutes. The model distinguishes three different types of organisations: Newcomers, Beginners and Pioneers. These outcomes are based on the results across six dimensions of the model. These dimensions are: Strategy and Organisation (1), Smart Factory (2), Smart Operations (3), Smart Products (4), Data-driven Services (5) and Employees (6). Every dimension consists of a few components where firms can reside from stage 0 (outsider) to stage 5 (excellent). The four main findings are: First, I4.0 must be embedded stronger in the strategy of the firm. Four out of the ten participating firms did not have adopted a strategy for I4.0 in their corporate strategy. Second, qualified staff is a decisive factor to achieve the transformation to I4.0 and most firms indicate to trust the competencies and learning abilities of their employees. Third, data-driven services and networked products enable new business models.

[203] See Rockwell Automation, unknown author (2014), p. 1-12.
[204] See Lichtblau et al. (2015), p. 70-74.
[205] See Lanza et al., (2016), p. 76-79.
[206] See Reinhard, et al. (2016), p. 28-33.
[207] See Jodlbauer/Schagerl (2016), p. 1473-1487.
[208] See Leyh et al. (2016), p. 1297-1302.
[209] See Kleemann/Glas (2017), p.35-41

Data-driven services and their added value are unidentified territories for almost all organisations. However, the exploitation of services that generate data is expected to offer lucrative results and initiatives to expand current business models. Fourth, the pioneers of I4.0 emphasise the need to secure financing of advancing I4.0 projects to avoid undue delays.[210]

### 5.2.3. *Self-assessment tool for digital operations by PwC*

As opposed to the scientific approach of the “Industrie 4.0 Readiness” model, PricewaterhouseCoopers applied a more practical orientation to structure their maturity model. The model developed by PwC assesses I4.0 capabilities across seven dimensions with four stages, ranging from digital novice (1) to digital champion (4). Their online self-assessment tool serves as a starting point for successive steps. The study of the consulting firm results in an advice of six steps to achieve success in the digital landscape. These six steps are: First, organisations are advised to evaluate their current maturity and then clearly define their vision regarding their digital strategy for the coming five years. Second, pilot projects can serve as proof of concept and demonstration of technologies. Setting up cross-functional teams that have the freedom to generate ideas that exceed the boundaries of the firm should be stimulated. Third, firms should verify the capabilities they need, with regards to organisational structures, people, collaboration processes and implementing new technologies. Fourth, collecting the right data in real-time and analysing it effectively is critical for forecasting and decision-making systems. Fifth, companies should create a culture where talented employees with technical skills feel at ease. A modern digital culture is characterised by an emphasis on collaboration, freedom to think beyond company borders, and welcoming to cooperation with external partners. Sixth, firms benefit from establishing partnerships with suppliers and customers by sharing knowledge and developing solutions together.[211]

### 5.2.4. *System Integration Maturity Model Industry 4.0*

Unlike the previous two maturity models that were aimed primarily at broad organisational aspects, the “System Integration Maturity Model Industry 4.0” (SIMMI 4.0) applies a more specific approach. The SIMMI 4.0 model highlights the importance of the IT infrastructure of

[210] See Lichtblau et al. (2015), p. 8-10.
[211] See Reinhard et al. (2016), p. 26-32.

the company by evaluating the readiness of a firm's IT landscape against the requirements of I4.0. A literature review by the authors resulted in a model of four dimensions, deduced from seven requirements for IT systems in the context I4.0. Below follows an explanation of the most important requirements from I4.0 literature.[212]

For IT systems in a I4.0 environment, vertical and horizontal integration are essential. Vertical integration of IT systems along the hierarchy of the organisation means that data from all enterprise support systems should be integrated. Optimally, I4.0 business processes in all levels of the organisation can exploit data from Enterprise Resource Planning systems, Supply Chain Management systems, Information systems and Product Life Cycle Management systems. At the same time horizonal integration must be established, meaning that the requested information is available where and whenever needed along the entire supply chain, including business partners. The aim of horizontal and vertical integration is to establish digital continuity. This means that the engineering of products, business processes, production systems are supported continuously and consistently. In addition, a service-oriented architecture, cloud computing, information aggregation and processing, and IT security are mentioned as pre-requisites for the implementation of I4.0.[213]

### 5.2.5. *Existing models aimed at purchasing with industry 4.0*

The maturity model "Reifegradmodell"4.0-Readiness" by Kleeman et al (2017)[214] is specifically tailored to purchasing with I4.0. The aim of the model is to serve as the first orientation for the development of a corporate "purchasing 4.0" strategy. The authors present a structured estimation of how Industry 4.0 is expected to change purchasing structures and processes. Their three sketched future scenarios for purchasing 4.0 are:

- Data as purchasing power;
- Business analytics;
- Strategic cyber-physical purchasing systems.

[212] See Leyh et al. (2016), p. 1297-1302.
[213] See Leyh et al. (2016), p. 1298.
[214] See Kleeman/Glas (2017), p.35-41

The purchasing 4.0 maturity model consists of eight dimensions: Connectedness (1), Relationships with Suppliers (2), Purchaser (3), Organisation (4), Autonomic Processes (5), Product Group Strategy (6), Digitisation Strategy (7), and, Enterprise IT (8). The large number of dimensions indicate the comprehensiveness of I4.0 for purchasing.

After an analysis to assess the purchasing function as-is, the authors recommend three successive steps for a roadmap towards purchasing 4.0. The first step is releasing sufficient resources for setting up a strategic framework derived from measurable enterprise goals. Second, aided by the maturity analysis current strategic and operational gaps should be identified. Third, from the results of the maturity analysis actions should be taken based on a priority analysis to balance feasibility against needs.

### *5.3. Ideal world scenario for the future of purchasing*

In the following section, an ideal world scenario of how purchasing could look like in the future by adopting I4.0 technologies. The scenario is structured according to van Weele's (2010) model of the purchasing function as illustrated in figure 5-1, which describes the consecutive steps of the purchasing process.

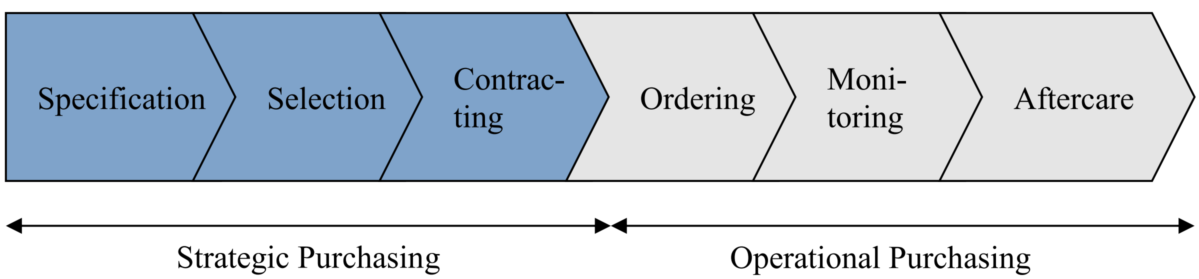


Figure 5-1 Model of the purchasing function
Source: Based on van Weele (2010)

#### 5.3.1. *The use of Artificial Intelligence and automated supplier selection is expected to enhance Strategic purchasing*

***Specification***

Specification concerns market research, specifying requirements and determining volumes. It is the most determining stage for the success of the purchasing process, because specification captures which goods or services could be purchased later. Since it has the largest influence on the total costs in the end, the freedom that this stage offers should be utilised efficiently for cost reduction.

Contrary to before, competition in the modern age is becoming less of an affair between single firms because of the increased dependence on resources of other companies[215]. Hereby, organisations are advised to operate more in a multi firm network context, as opposed to isolated individuals, to stay competitive. Though firms are advised to mutually exchange resources, they can still sustain competitive advantage through a distinctive company culture that is difficult to imitate[216]. Industry 4.0 facilitates the sharing of resources with the introduction of interlinked supply chains, where companies digitally collaborate and share information in real time. With purchasing 4.0, effective relationship management with internal departments and external partners will likely become even more crucial than today as the dependency on shared resources increases[217].

A system that uses Artificial Intelligence to identify new suppliers, products and services on the market could support purchasers during the specification phase. In its simplest form, this system could be a database that hosts all suppliers and their offerings in an electronic catalogue with a universally used template. Then, since the system holds complete information of the offered goods and services, it could give users intelligent suggestions for alternative products that satisfy the needs of the buyer as well.

Ideally, the system would also contain information regarding lead times, capacity and other relevant information, so-called “supplier scores”. The information regarding supplier scores would dynamic however, since not every customer is as important for the supplier. For end-users, the tool could have the appearance of a social network, as they are already familiar with using Facebook, Twitter, LinkedIn etc. An industrial “social network” would be a convenient tool for transparency, as it presents a complete overview of the supply chain and possible interchangeable suppliers with their offerings. Simultaneously, the system presents an approachable method for managing relationships with first-, and second-tier suppliers, and

[215] See Dyer/Singh (1998), p. 675-676.
[216] See Barney (1986), p. 663-664.
[217] See Jarratt (2004), p. 303-304.

beyond. When the system is easy accessible, it would also support SME's in their search to increase brand awareness.

### *Selection*

After specifying the requested goods or services, a selection is made of suppliers that meet the requirement of the buyer. In case the offerings themselves are identical or substitutable, suppliers distinguish themselves on the base of e.g. available capacity, lead times, annual cost-reduction, responsiveness, and of course, price. The perceived importance of the supplier characteristics is subject to the interests of the buying organisation, but the selection criteria for suppliers should follow the purchasing strategy. Good criteria should exceed acquisition costs by including all factors that impact supply chain performance[218]. After arranging selection criteria, supplier scores can be derived systematically by an automated process.

The automated supplier selection process could look like selection procedures in manufacturing where products are transferred automatically to the machine with available capacity. Figure 5-2 illustrates a concept for automated supplier selection where selection criteria are based upon the purchasing strategy, followed by automated decision making. In this case, the dynamic supplier scores of three suppliers (A to C) are compared, after which a system automatically selects the supplier that best fits the selection criteria of the buyer.

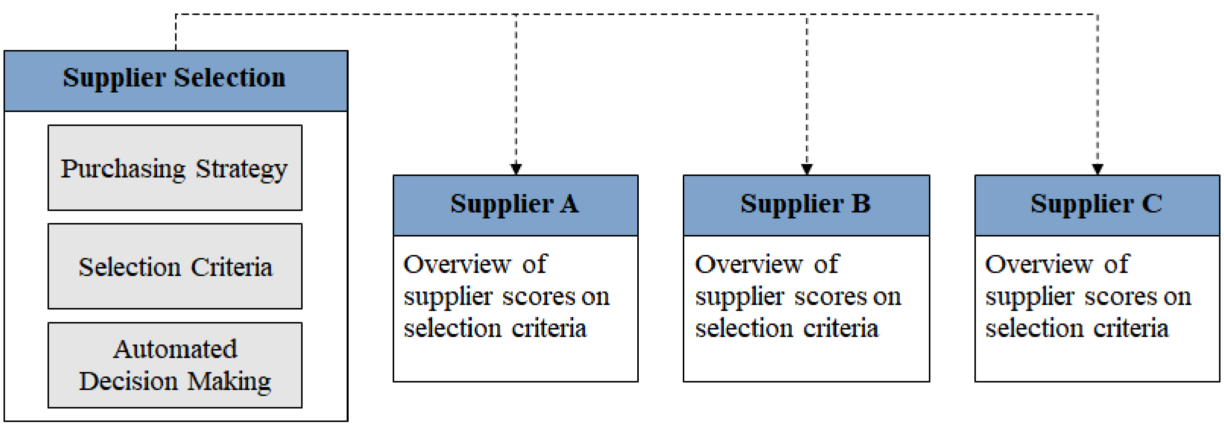


Figure 5-2 Automated supplier selection process

[218] See Ha/Krishnan (2008), p. 1306.

### *Contracting*

The contracting phase encompasses negotiations with suppliers and closing contracts. A multi-bilateral negotiation is an exchange mechanism where multiple buyers negotiate with multiple sellers. The resulting interactions between buyers and suppliers create a dynamic exchange mechanism for trade, because all parties have alternative options to close a business deal in their best interest. To obtain the optimal outcome, different scenarios are conceivable; Either buyers enter a confrontation with a supplier, aim for a win-win situation by collaborating with a supplier, or adopt a combination of both strategies. In contrast, single-sided auctions are more static processes where sellers remain passive and buyers are engaged in competition to seal the best deal.[219]

Currently, e-procurement systems facilitate electronic marketplaces where online exchanges and auctions take place in a business-to-business setting. However, three shortcomings of existing digital negotiation systems are: Exchanges offer a value proposition that is mainly targeted at competition on price (1); Hereby the systems are in the best economic interest of buyers and thus offer a single-sided incentive, in contrast to aiming for win-win situations (2); Off-the-shelf software packages poorly match with the priorities of their customers and the usage of various generic software offerings creates market fragmentation and opposes transparency (3).[220] Nevertheless, it is a safe prediction that the share of automated digital negotiations, in relation to their traditional face-to-face counterparts, is expected to grow in the digital age.

In the future, digitalised contracting could develop towards the adoption of blockchains. Blockchains let members of a distributed peer-to-peer network interact with each other in a transparent, auditable manner, without the intervention of an intermediary[221]. Purchaser and sellers can store information regarding their preferences for characteristics of goods or services in a blockchain. For example, desired quality, price range, lead times, reliability of the business partner, etc. Then, the blockchain will automatically engage in a negotiation procedure when an opposing party has been found that meets the required criteria. The negotiations themselves

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[219] See Kersten (2011), p. 3-4.
[220] See Wise/Morrison (2000), p. 2-4.
[221] See Christidis/Devetsikiotis (2016), p. 2292-2293.

could be outsourced to digital assistants, so-called 'avatars' that represent the interests of the involved parties. The avatars should have Artificial Intelligence, so they can act like human negotiators when the contracting systems leave room for coping dynamically with the prescribed demands.

#### 5.3.2. *In operative purchasing autonomous ordering is expected*

***Ordering, Monitoring, and Aftercare***

In operative procurement, self-filling systems that autonomously order products from shared electronic catalogues, seem likely to automate the ordering process. For orders that are carried out manually, technological restrictions can be added to processes to exclude the possibility of maverick buying. During monitoring, the processes of initiating a requisition, approving it, and raising an order, can probably be fully automated in the near future. For aftercare, a feedback loop that collects and analyses information of supplier evaluations during the entire product life cycle. When this feedback is shared with supply chain partners in an integrated supply chain, this will contribute to increased transparency and possibly better performances of supply chain partners.

### *5.4. First steps into purchasing with Industry 4.0: a maturity model from standardisation, through integration and automation, into autonomous decision making*

#### 5.4.1. *A model of four stages is preferable to cover all relevant dimensions that describe maturity*

Recurring themes and similarities in the examined maturity models in (5.2) are: the importance of defining a digital strategy, the importance of qualified staff, and the possibilities that I4.0 offers for developing new business models. Since purchasing is of key importance for organisations and represents a part of every step across the value chain, zooming in on a maturity model for I4.0 specifically for purchasing is meaningful. Due to its large financial influence, implementing purchasing 4.0 successfully could be decisive for the progress of the distribution of I4.0 concepts within firms.

For our proposed maturity model, a literature analysis was conducted to discover the phenomenon Industry 4.0 with the aim of acquiring a better understanding of how to connect

I4.0 with purchasing. Thereafter, existing maturity models for both I4.0 in general and specifically for purchasing with I4.0 were analysed. The result is a maturity model of four stages with 26 questions for assessment that are fully formulated for every stage, so 104 descriptions in total.

Some maturity models apply three or five stages. However, four stages have the following two advantages, compared to such models. First, the boundaries of stages are more clearly defined compared to models with three stages, because the stage in the middle is split in two distinctive groups. Second, the three central stages of models using five stages tend to become ambiguously since the differences between stages are too small. Thus, a model of four stages is preferable to cover all relevant dimensions that describe maturity.

The four stages used in the model are structured based on the guidelines by Schiele (2007)[222]:

*Stage* 1: “A particular best practice activity/tool/method is known within the organisation.”

*Stage* 2: “A position or person is assigned to perform the task.”

*Stage* 3: “The process for completing the task is defined and documented as well as applied.”

*Stage* 4: “Cross-functional integration in the company is assured while basic requirements are met.”

[222] See Schiele (2007), p. 278.

### 5.4.2. *A high-level overview of four stages shows the key focus points that serve as the foundation for a detailed maturity profile*

In a recent master's thesis, a high-level roadmap design for 2017 to 2021 onwards was presented[223]. The roadmap proposes four steps towards Industry 4.0: Standardisation, Integration, Automation and M2M communication. Inspired by results of the roadmap, our maturity model continues this previous research. The stages in the maturity model mainly correspond with Hazelaar's (2016) work. Likewise, the first step is ensuring standardisation I4.0 processes. Next, integration within the own organisation, thereafter automation with M2M communication and/or CPS, and closing, proficiency in autonomous decision making. The four stages used in the maturity model for purchasing with Industry 4.0, from digital novice to digital champion, are described as follows:

***Digital novice:*** "Industry 4.0 concepts are in a pre-mature stage within separate departments, pilot-projects and novice use of data analytics. Industry 4.0 processes are not standardised within the firm yet."

***Vertical integrator:*** "Cross-functional collaboration and alignment of digital strategy between departments, advanced use of data analytics. Standardised I4.0 processes are present in the organisation."

***Horizontal integrator:*** "Integration of processes outside the boundaries of the firm, competent use of data analytics, machine-to-machine communication, and/or cyber-physical systems. Standardised I4.0 processes are present, and people in the organisation are responsible to ensure compliance."

***Digital champion:*** "Industry 4.0 concepts fully aligned with corporate strategy across Integrated supply chains, proficient in applying autonomous decision making, machine-to-machine communication, and cyber-physical systems."

[223] See Hazelaar (2016), p. 58-60.

*5.5. Our maturity model is based on a model for a design process and consists of eight layers*

We introduce a tool to assess the maturity of Industry 4.0 within purchasing departments of industrial firms. Our maturity model provides guidance to organisations for a systematic adoption of Industry 4.0 in purchasing. The design process of the maturity model is based on a general model for a design process proposed by Van Aken et al. (2012), shown in Figure 5-3.

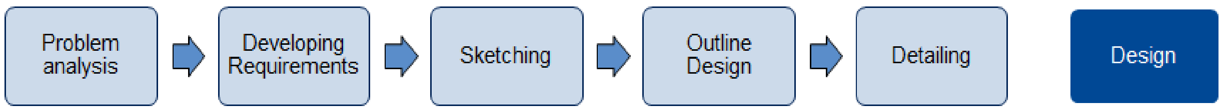


Figure 5-3 General model for a design process
Source: based on Van Aken et al. (2012)

During recent workshops, purchasing managers indicated their organisations mostly have not even completed the third industrial revolution. Thus, a to provide purchasing managers Our maturity model incorporates eight categories that include all relevant aspects for the transformation towards purchasing 4.0.

In the eight categories, illustrated by figure 5-4, the following questions are central:

***Strategy: Is digitisation integrated in the corporate strategy?***

Strategy is the first and foremost category in the maturity model since it indicates where purchasing departments are expected to start the conversion towards the fourth industrial revolution. Organisations in stage four possess a digitisation strategy for systematic adoption of Industry 4.0 concepts across departments following a structured a roadmap for the coming years with a clearly defined vision for implementing Industry 4.0 gradually. Further, the digitisation strategy is regularly updated, adjusted to corporate strategy, and aligned with the purchasing function.

***Process: Are our processes standardised, digitised and automated?***

Our expectation is that by adopting I4.0, processes are not only standardised, integrated, and automated but also autonomous systems have taken over tasks in both operational and strategic procurement. In the highest level of the maturity model, 90 per cent or more of the total purchasing volume is purchased through procure-to-pay suites and e-procurement is supported by M2M communication. In addition, decision support systems based on artificial intelligence are authorised to autonomously make decisions with a high impact.

***Physical level: Is the connection between physical systems established?***

In the future, a fusion of real and virtual systems is expected. Hence, in the fourth level includes seamless integration of both worlds, and demand generation supported by CPS and M2M communication. Moreover, order data is analysed in real time, and automatic ordering takes place autonomously.

***Purchase-to-Pay: Is the payment process automated?***

Modernisations to improve the payment process can be expected as well. Technological restrictions (e.g. by M2M communication) can be deployed to make ordering goods outside existing procedures impossible, thereby effectively excluding so-called maverick buying. In addition to the physical part of automatic ordering, the process side is expected to be automated as well, by engaging artificial intelligence as a self-learning system.

***Controlling: Do we have complete, real-time transparency?***

A central business intelligence system that assumes data analysis for the entire organisation allows for complete, real-time transparency, meaning that information, relevant for purchasing managers, is accessible anywhere, anytime. Further, predictive analytics in real-time, assisted by decision support systems and continuously improved by self-learning algorithms, is also included in the final stage of the maturity model. Nonetheless, protection against misuse of data (e.g. unauthorised access, modification, or destruction) is equally important as exploiting the new possibilities of data analytics. Therefore, digital champions strictly protect their data, provide openness on how this is done, and let independent organisations regularly check the cyber safety of the organisation.

***Sourcing: Is the strategic purchasing process supported?***

Currently, data analysis is commonly used to predict demand, based on data traffic from web shops. Despite, firms are expected to benefit more from data analyses when the results are shared within the organisation by connected systems. Ideally, predictions are adjusted in real time and directly influence supply demand physically through CPS and M2M communication. Digital champions use E-procurement systems to handle 95 per cent or more of the total purchasing volume and outsource negotiations to digital assistants. When the control of artificial intelligence by the organisation reaches a mature state, then autonomously operating digital assistants can be deployed to take over influential decisions within strategic purchasing.

***Suppliers: Are the suppliers prepared and willing to integrate Industry 4.0?***

World class suppliers collaborate closely with buying organisations through digitally integrated supply chains and both parties are fully involved and equally dedicated to collaborating. In addition, excellent suppliers take the responsibility for transferring required knowledge to less capable supply partners, so the overall performance increases.

***Employees and Users: Are the employees prepared and willing to integrate Industry 4.0?***

The evolution from the third industrial revolution towards I4.0 requires users to adapt to changing working methods. Accordingly, purchasing managers are recommended to assess whether their employees possess the required capabilities (willingness to learn, holistic thinking, proactivity, inventiveness) to undergo the transition. In organisations in stage four, managers not only actively stimulate learning and development, but also regular assessments and evaluation take place to ensure the knowledge of employees matches current developments.


Figure 5-4 Visualisation of the maturity model

# 6. CONCLUSION: PURCHASING CAN PROGRESS AND BENEFIT INDUSTRY 4.0 BY ADOPTING NEW TECHNOLOGIES TO IMPROVE CURRENT PROCESSES

The aim of the research was to explore possibilities how the purchasing function can employ the technologies of Industry 4.0 during different stages of the purchasing process. Since the fourth industrial revolution has started only recently, this study had an exploratory nature. The hypotheses, consisting of combinations of technologies and stages during the purchasing process, were derived from literature on Industry 4.0-based manufacturing, enabling technologies of I4.0 and purchasing and supply management. Below, our four research questions are answered.

## *6.1. Which characteristics defined the three industrial revolutions preceding Industry 4.0 as revolutionary?*

The three industrial revolutions preceding I4.0 share three recurring components that characterise them as revolutionary. First, a prologue, this is a global or national development that demands to solve challenges, current for the time being, with technology. Second, research on and development of a key technology is stimulated with the aim of deploying this new technology in the industry. Third, an organisational change couples the adoption of new technologies. During each revolution, the introduced key technology lead to new methods of operations. This required an adjustment of the applied management style to suite the new working ways better.

## *6.2. Which attributes qualify Industry 4.0 as an industrial revolution?*

Similar to its predecessors, the fourth industrial revolution again has a prologue, a key technology and an organisational change. The demand is a changing competitive environment with a trend towards co-creation and mass customisation by customers while maintaining the need to produce efficiently and guarantee fast delivery times. Meanwhile, East-Asian competitors have caught up in the quality of manufactured goods, so a traditional competitive advantage of Western manufacturers is under pressure. The key technologies of I4.0 that are expected to transform the industry are Big Data analytics, Machine-to-Machine communication, and Cyber-Physical Systems. These three key technologies rely heavily on information and communication. The literature suggests that extensive collaboration within and outside the firm is needed to benefit optimally from exchanging and utilising information, so cooperation between different departments and with supply partners is encouraged to make the switch to I4.0.

### *6.3. Which enabling technologies are currently associated with Industry 4.0?*

As mentioned earlier, Big Data analytics, Machine-to-Machine communication, and Cyber-Physical systems are associated with Industry 4.0. Roughly speaking, these technologies represent three aspects that together facilitate I4.0, thereby emphasising that all three are required. First, data from sensors and Big Data analytics is processed to useful information. Second, Machine-to-Machine communication transmits the information to all involved actors (e.g. embedded systems, machines, and humans). Third, the analysed and communicated information is used by Cyber-Physical systems that autonomously make decisions based on the data that is provided and the conditions of the environment at that time. Especially Cyber-Physical systems are distinctive for I4.0, because these systems can make their own decisions. Compared to the third industrial revolution, the digitisation of the industry, this is an important step forwards.

### *6.4. What is the current state of art of the enabling technologies supporting Industry 4.0?*

From literature, the expectations for I4.0 are high and substantial financial resources are concerned with its success. However, for most companies it remains unclear what I4.0 implies, so it is still regarded as a buzz word by many. Due to this uncertainty, existing implications are often rebranded as I4.0 while they are in reality still Industry 3.0. Therefore, especially in this early stage of the development of I4.0, maturity models are useful tools to support organisations by guiding them systematically through the transition towards I4.0. Based on the assessed maturity of the organisation, focus areas for improvement should be specified. Thereafter, for a complete overview, roadmaps where goals are plotted against time, can be developed.

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