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The Impact of Industry 4.0 on the Supply Chain

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HICL



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The Impact of Industry 4.0 on the Supply Chain

Hans-Christian Pfohl, Burak Yahsi and Tamer Kurnaz

Disruptive innovations are currently changing the landscape of many industries and their business models. Because of increasingly digitalized processes and an exponential growth of sensible data, supply chains are also impacted by the fourth industrial revolution. The strategic management requires a more transparent understanding of the currently available and interrelated technologies and concepts. Since the supply chain will obviously undergo an organizational change, a theoretical framework is necessary to understand which activity is impacted from a holistic management-perspective. In this paper, the term “Industry 4.0” is defined and its seven characteristic and interrelated features are highlighted. Furthermore, related technologies and concepts are validated to determine their contribution to the future development of the industrial revolution. Out of initially 49, the 15 most relevant technologies and concepts are identified through a conceptual analysis. A theoretical framework is proposed to evaluate key technologies and concepts with respect to their impact on the supply chain. According to Cachon (2012), three interesting hypothesis are stated, concluding on the impact of Industry 4.0 from a structural, technological and organizational perspective. All results are based on a structured literature review.

Keywords: Industry 4.0, Supply Chain, Organizational Change, Innovation

1 Introduction

First, the development of steam machines drastically changed the production processes. Electrical drives, combustion engines and the innovative assembly line production systems then initiated the second industrial revolution. The third industrial revolution was mainly characterized by the enormous automation of the production processes (Bauernhansl, ten Hompel and Vogel-Heuser, 2014), which is the basis for the ongoing fourth industrial revolution, where we face complex systems of hardware, data centers and software components in one single product (Brettel, et al., 2014). Traditional barriers for products and their value proposition are extremely extended and therefore, existent value chains and the respective supply chains are to be rethought (Porter and Heppelmann, 2015).

As an early example, General Electric started a billion-dollar-project in 2011 to install sensors in their production-machinery and to invest in product-embedded software (Iansiti and Lakhani, 2015). Whilst many more companies are already investigating how to react to the current trend of implementing "Industry 4.0" technologies and concepts, recent research with respect to this term is highly diverse and limited to the operational implementation of technologies and concepts on the production process-level (Herman, Pentek and Otto, 2015).

Figure 1 visualizes the fact that most scientific papers and articles with respect to "Industry 4.0" can be allocated to cluster A. Here, the research is focusing exploratory questions on how "Industry 4.0" technologies and concepts can be implemented within the company's supply chain on the process-level (Bauernhansl, ten Hompel and Vogel-Heuser, 2014; Parlikad and McFarlane, 2010).

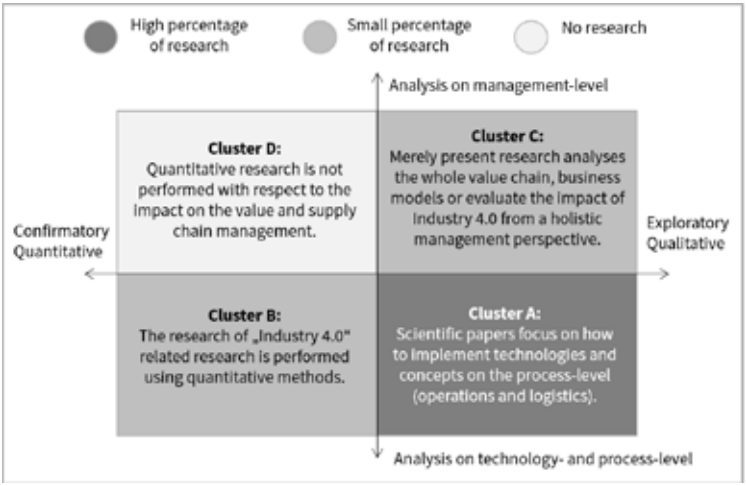


Figure 1 Clustering the research-fields with respect to “Industry 4.0”

The confirmatory research in cluster B adds quantitative methods to the analysis and provides implementation models for specific technologies (Mohanarajah, et al., 2015). This paper can be allocated to cluster C, as it widens the horizon of the currently explorative research to the management-level. Based on a structured literature review, a theoretical framework is developed and applied to understand the impact of the fourth industrial revolution on the supply chain from a holistic management-perspective. This qualitative analysis will be the basis for further quantitative research in cluster D, where the hypotheses in this paper can be validated in expert interviews and questionnaires.

All research results given in this paper are based on a structured literature review executed according to Baker (2000) and Cooper (1988). This review includes high-rated international journals which were published since

2010. The following journals were selected according to the VHB-ranking of Hennig-Thurau (Walsh and Schrader, 2014) and their relevancy with respect to the scientific topic: Management Science, Operations Research, Journal of Management Studies, Organization Science, M&SOM, Transportation Science, Information Systems Research. Other scientific databases like EBSCOHOST were added to sources of the literature review, as currently most of the relevant published articles with respect to "Industry 4.0" can be found in scientific magazines and lower-rated journals. Studies published by companies (e.g. consulting firms like Roland Berger) or research institutes were validated as well and bring up interesting hypotheses and results, especially in the German literature. The key words were chosen according to the research topic and the included technologies and methods described within this paper. Articles and studies identified by a keyword-search were first validated by their title, their abstract and then by their content with respect to their relevancy. In total, 674 published articles, scientific papers and books were reviewed throughout this analysis.

2 Management Approach

In this chapter, a management approach is proposed that supports the companies to understand which organizational changes are to be expected for their respective supply chain (figure 2).

First, the strategists must make the term "Industry 4.0" and its characteristic features more transparent and communicate a common definition to all company members. At this stage, it is important for all executive members

of a company to know which levers can be tackled to enable and to streamline the innovation adoption process in the organization and in the supply chain. Chapter 3 helps the organizations by stating a definition of the term "Industry 4.0" and highlighting its characterizing features.

Second, relevant technologies and concepts have to be identified, clustered and analyzed by the corporate management according to their relevancy for the company. Chapter 4 brings up a mind-map of all currently discussed technologies and concepts with respect to the research-field of "Industry 4.0". These are clustered into four dimensions and allocated to the earlier described characteristic features. A conceptual selection process is developed and applied to evaluate the relevancy of all technologies and concepts according to the characterizing features of the term "Industry 4.0". The strategic management of a company may apply the same approach to identify respectively relevant technologies and structures within workshops.

Third, the management needs to evaluate how their supply chain will be impacted by the relevant technologies, i.e. which challenges and potentials are to be expected with respect to the primary supply chain activities. Chapter 5 proposes a theoretical framework that allows the evaluation of the impact of each relevant technology with respect to their impact on the supply chain from a holistic management-perspective. At the end of chapter 5, three main hypotheses are proposed after executing the analysis for all relevant technologies and concepts.

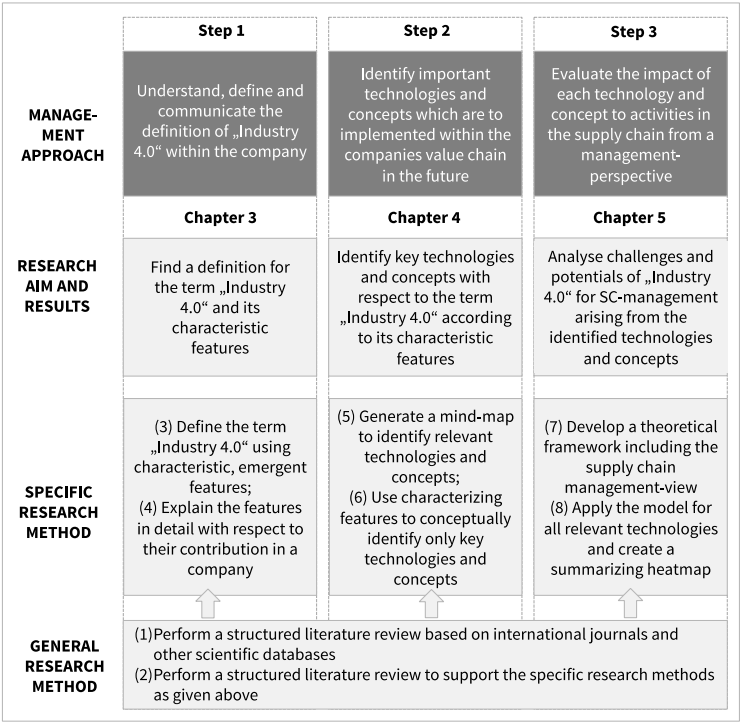


Figure 2 Management approach and the relevancy of single chapters

3 Defining the Term "Industry 4.0"

Since the term "Industry 4.0" is not ultimately defined (Brettel, et al., 2014), this paper states a definition using characterizing features. All currently discussed characteristic features of the term "Industry 4.0" were collected based on the structured literature review and included within a conceptual analysis, in which all mentioned technologies and concepts in chapter 4 were validated with respect to the question: Does this technology or concept enable innovations in the supply chain of an organization according to the specific characteristic feature? For example, the technology of Cloud Computing enables digital processes and value propositions (this means a count for the feature "Digitalization") and increases the modularization and scalability of products, processes and facilities in the supply chain (this means a count for the feature "Modularization").

Figure 3 summarizes the results of the analysis for all 49 technologies and concepts. The features marked dark are the most relevant (above 30 counts) and hence, these are used to define the term "Industry 4.0" and are explained in detail. The result leads to the following definition: Industry 4.0 is the sum of all disruptive innovations derived and implemented in a value chain to address the trends of digitalization, autonomization, transparency, mobility, modularization, network-collaboration and socializing of products and processes. In the following, the seven characterizing features are reflected and described in detail.

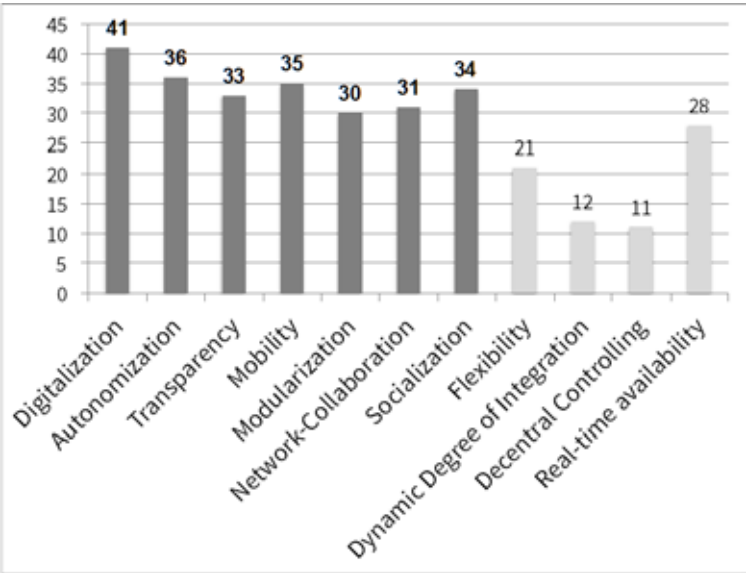


Figure 3 Results of the analysis of characteristic features

(1) Digitalization: The companies' internal processes, product components, communication channels and all other key aspects of the supply chain are undergoing an accelerated digitalization process (Geisberger and Broy, 2012). According to the conceptual analysis visualized in figure 3, the digitalization process itself is the most important characteristic feature and enables all other characterizing features.

(2) Autonomization: "Industry 4.0" technologies and concepts are enabling machines and algorithms of future companies to make decisions and perform learning-activities autonomously. This autonomous decision-making

and learning is based on man-made algorithms and enables whole factories and manufacturing facilities to work with minimum human-machine-interaction (Angelov, 2013).

(3) Transparency: While global supply chains are characterized by highly complex structures, the available "Industry 4.0" technologies are increasing the transparency of the whole value creation process. Through this increase in transparency, decision-making in the company will be more collaborative and efficient. Not only the supply chain processes, but also the behavior of corporate partners and customers will be more transparent to the company (Wang, Heng and Chau, 2007).

(4) Mobility: The dissemination of mobile devices makes communication, data sharing and generation of values possible from all over the world. The mobility of devices is changing the way customers are interacting with companies, and the communication and interaction of machines in the production process (Schweiger, 2011).

(5) Modularization: "Industry 4.0"-technologies are enabling the modularization of products and the whole value creation process, e.g. manufacturing facilities. Modular production facilities can be adjusted in their quantity autonomously, which is increasing the flexibility of the production processes (Koren, et al., 1999; Putnik, et al., 2013).

(6) Network-Collaboration: Just as human beings in our society are interacting in social networks, the companies' processes will be defined and activities will be decided through the interaction of machines and human beings within specific networks in and out of the companies organizational borders (Bauer, et al., 2014).

(7) Socializing: The collaboration in networks is enabling machines (not only smartphones) to start communicating and interacting with other machines and/ or humans in a socialized manner. Herewith, the collaboration with machines is socialized, since humans are able to get into a conversation with the machines (Oswald, 2014).

4 Identify Key Technologies and Concepts

The next goal of this paper, and the second step according to the management approach, is to understand the relevance of the many interrelated technologies and concepts discussed with respect to the fourth industrial revolution. For this purpose, a three-step approach was applied. First, a structured literature review was performed to create a mind-map (figure 4). This mind-map summarizes frequently discussed technologies and concepts within the validated literature and allocates them to the previously identified key characteristics of “Industry 4.0”. As shown in the mind-map, the technologies and methods can be summarized into four clusters according to the highest relevance of the earlier described characteristic features. During the evaluation of a specific technology or method, the corporate management may use this mind-map to understand its interrelations with other technologies.

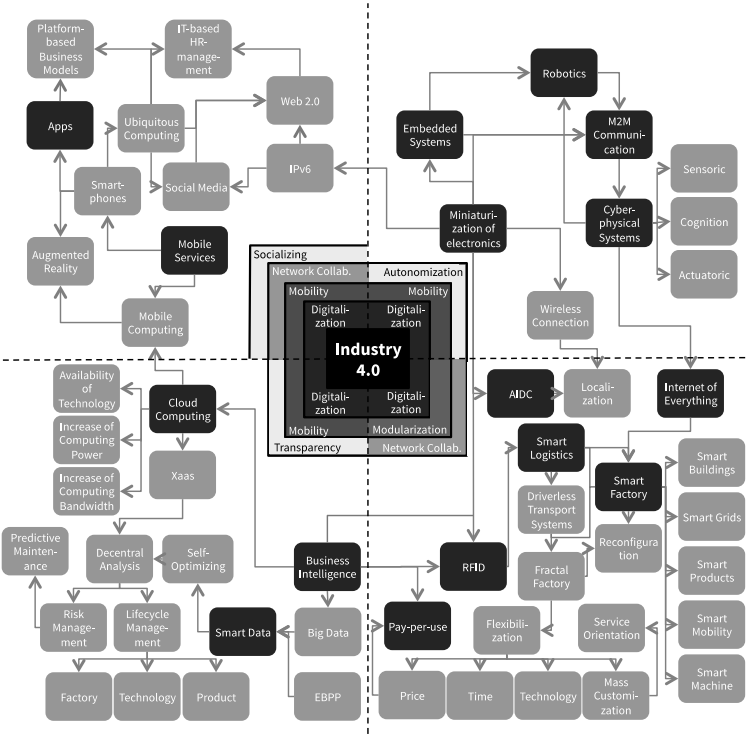


Figure 4 Mind-map of discussed technologies and concepts within the relevant literature

Second, all technologies and concepts were conceptually validated to understand whether or not these are enabling the digitalization, autonomization, transparency, mobility, modularization, network-collaboration and socialization of processes and products within the supply chain. Hence, figure 5 sorts all technologies of the mind-map according to the number of the respectively supported characterizing features of “Industry 4.0”.

According to the analysis of this paper, the most relevant and contributing technologies and concepts are in the far left part of the density-function given figure 5 and are discussed in detail in the following.

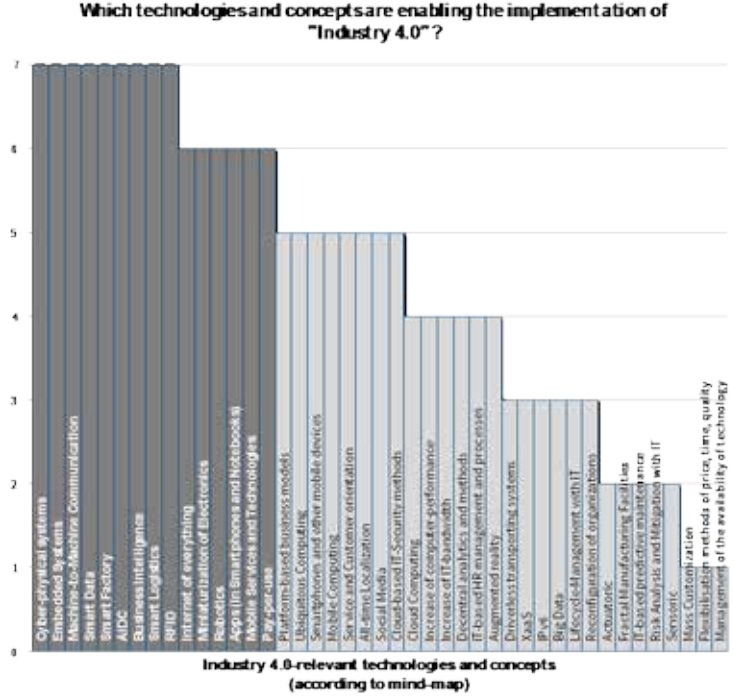


Figure 5 Density-function to validate the importance of technologies and concepts of “Industry 4.0”

A very important technology is the miniaturization of electronics, which means the manufacturing of smaller mechanical, optical and electronic products and devices (Feldmann, Franke and Schüßler, 2010). It is a main enabler for the automatic identification and data collection (AIDC) and radio-frequency identification (RFID) technologies, which help to collect, manage and analyze data within transportation processes in the supply chain (Smith and Offodile, 2002). In fact, AIDC- and RFID-technologies belong to the so-called embedded systems. These are microprocessor-based systems, which are built into physical products to control a function or a range of functions (Heath, 2002). On the other hand, the field of Robotics is closely related to the miniaturization of electronics as well, as it is the branch of technology that deals with the design, construction, operation, and application of robots (Demetriou, 2011). Machine-to-Machine Communication (M2M) can be described as the autonomous and bilateral communication of machines (Zaus and Choi, 2014).

Business Intelligence (BI) is often referred to as the techniques, technologies, systems, practices, methodologies, and applications that analyze critical business data to help an enterprise better understand its business and market and make timely business decisions (Chen, Chiang and Storey, 2012). Based on the BI-technology, the concept of a Smart Factory increases the information transparency and enables the autonomous control of a manufacturing facility (Radziwon, et al., 2014). When pay-per-use licensing is applied within smart factories, pricing is based on the actual amount of the used software, measured in units of use, such as the number of users or the number of transactions (Tukker, 2004). The term of the Smart Factory includes the concept of Smart Logistics, which describes the

application of ubiquitous technologies to logistics processes for efficiency improvements in transport, warehousing and storage processes (Resch and Blecker, 2012). Smart Data, as a related concept, helps to collect, manage and analyze data from across an increasingly complex investment universe. Big Data, the massive collection and storage of data in real-time, becomes Smart Data when its objective is understood (Klinck, 2014).

5 Impact of Industry 4.0 on the Supply Chain

This paper proposes a theoretical framework to assess challenges to and potentials of the supply chain management arising from the fourth industrial revolution (visualized in figure 6 and 7 below). The vertical dimension reflects the supply chain according to MEYR and WAGNER (2004 cited in Kannegiesser, 2008, p. 14) with the categories procurement, production, distribution and sales. Herewith, core activities in the supply chain are captured. The horizontal dimension is oriented towards the model of LEAVITT (1965, pp. 1144-1170), who has developed a theory with respect to organizational changes and finds answers to the following question: By which variables is the innovation adoption process in a company impacted? According to this theory, every organization consists of four interactive and highly interdependent components: people, task, structure and technology. It is the interaction between these four variables that determines the success of organizational changes. While the variable “people” obviously refers to the human domain within an organization, this framework includes all human-related issues, from hiring and education of the personnel to the interaction of the organization in social systems out of the borders of the own

supply chain. According to LEAVITT, the variable “structure” means all systems of communication, systems of authority, and system of workflow within an organization. This paper sticks to this definition. The variable “technology” is described as assets - either physical assets like machinery or knowledge-based ones like patents. Since the tasks according to LEAVITT are redundant to the primary activities given in the vertical dimension, this component is excluded from the theoretical framework. The combination of both theories creates a theoretical STP-framework enabling a holistic view on the management issues arising from the planned and ongoing implementation of “Industry 4.0” technologies within the supply chain. At this stage, the strategic management of an industrial company must have evaluated which specific characterizing features of “Industry 4.0” are important for their respective supply chain activities, and must have identified relevant technologies and concepts according to the method given in chapter 3 and-4.

This paper evaluates the impact of all technologies identified and classified as relevant in chapter 4. Figure 6 summarizes the results in a heat-map. Note that during this analysis, weighting factors were not used. For example, the results for the technology CPS were included within the summarized heat-map with one single point each in the respective field. This is valid for all validated technologies and concepts. This heat-map will be used in the following to state three main hypotheses with respect to the expected organizational changes from a structural, technological and humanistic perspective.

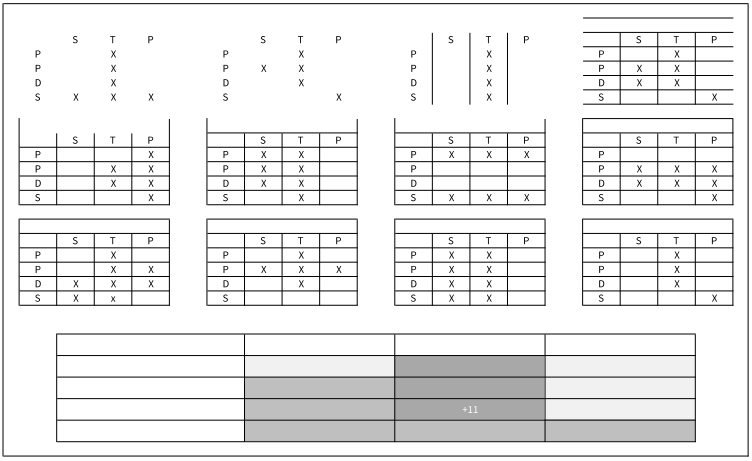


Figure 6 Summarizing view of the impact analysis in a heat-map

With respect to the structural variables described by LEAVITT, we understand from the density function given in figure 6 that the biggest impact and organizational changes are to be expected for the production and distribution processes. Whilst the sales processes face a relatively moderate impact from the “Industry 4.0” technologies and concepts, the procurement processes are impacted least. The biggest impact on the structure of the supply chains is to be expected from the concepts of Smart Logistics and Smart Factory. With their implementation, the whole supply chain will be affected from a structural and technological perspective, as all supply chain activities undergo a digitalization process. For example, Smart Factories will include intra-logistic processes which support the manufacturing systems with sophisticated applications, such as cyber-physical systems and driverless-transporting-systems execute intra-logistics processes within the manufacturing factory of companies (Dangelmaier, et al., 2001).

The distribution activities will be rethought and new technologies will be implemented as well (Kawa, 2012), since with transporting systems performing autonomous decisions based on pre-implemented algorithms, the logistics processes are already within the autonomization process (Coyle and Ruamsook, 2014). Algorithms may also enable products to make autonomous decisions during outbound-logistics activities in the digitalized supply chain of the future. This could be a real-time analysis of the currently existent quality on their way to the customer. Autonomization in logistics therefore means the autonomous decision-making, controlling, planning and initiation of logistics activities (Broy, 2011). Robotics may reduce the costs of production that arise from a reduced dwell-time and automated processes (Potkonjak, et al., 2000). Even the IoE will have an influence on the structural organization of supply chains. For example, the company's supply chain management could install an algorithm which reacts to bad-weather information autonomously and chooses a different transporting system (Li, et al., 2014). With the details given above, and the score shown in the heat-map (figure 6), we come up with the following first hypothesis: The supply chain will undergo an organizational change mainly with respect to the production and distribution processes from a structural perspective. The most impact will arise from the M2M-communication, and Smart Factory including Smart Logistics.

In the following, we examine the expected organizational changes with respect to technological variables. Compared to the other two variables "structure" and "people", organizational changes on the supply chain due to technological developments come out on top. Furthermore, we understand that the biggest impact is to be expected within the procurement,

production and distribution processes. Within our following detailed impact analysis, we limit our documentation to the technologies and concepts which have an influence on all supply chain activities (see figure 6). Through the miniaturization of electronics, the costs of transporting, warehousing and production can be reduced (Keyes, 2000). Based on this miniaturization process, AIDC- and RFID-technologies enable the digitalization process of the supply chain, and deliver real-time information about the current status of logistics activities. With this, the truck-delivery of specific products could be optimized (Lee, Padmanabhan and Whang, 2004; Geisberger and Broy, 2012). For example, the delivery information of transported products could be changed in real-time and whenever needed (Whang, 2010). This way, a product that is already on its way to the initially targeted customer could be routed to another nearby customer if the delivery was aborted. Hence, with the digitalization of all logistics processes through AIDC- and RFID-technologies, even problem management can be carried out centrally and online. For example, truck drivers may easily communicate with other machines (e.g. the loading area of the target delivery location) and inform the company about the expected delivery time (Botthof and Hartmann, 2015). Machine-to-Machine Communication impacts the supply chain, as it enables the automated recording and communication of process information in the production facilities and in the distribution networks. It furthermore supports the maintenance of machines, provides new paying methods for the sales function of a company and new services such as fleet management or track and trace systems. Challenges with respect to the machine-to-machine communication arise from the need for standardized communication protocols and cyber-security (Chen,

Wan and Li, 2012). Technologies and IT-infrastructure elements, which fall under the term Business Intelligence, will impact the supply chain activities through cost-reduction opportunities and an increase of the process-transparency. Furthermore, processes will be more digital and technological, where the company's personnel are able to acquire and share information using the BI-technology from anywhere (Zheng, Fader and Padmanabhan, 2012). Especially procurement processes can be optimized, as suppliers can be fully flexible and autonomously chosen by specific software (Mishra and Agarwal, 2010). Smartphone apps, as described in chapter 4, will have an impact on the organization of the supply chain activities from a technological perspective as well. In future, each employee will be equipped with this kind of mobile devices, interact with colleagues, perform time-management and execute specific activities in the manufacturing process with the smartphone. Specific apps will be created to enhance the efficiency of the production processes, e.g. a track and trace system of specific product components, or by assisting software for the human activities in the company. A leading industry which is already including the smartphone apps within its supply chain is the medical industry (Xu, et al., 2011). With this analysis, we come to the following hypothesis: If companies implement Industry 4.0 technologies and concepts, the supply chain will mostly undergo a technological change, and mainly with respect to the procurement, production and distribution processes. The biggest influence will arise from BI-technologies, Smartphone Apps, AIDC- and RFID-technologies and the miniaturization of electronics.

The smallest organizational changes are to be expected from the variable "people". Despite the sales processes, where interactions with customers

will face a huge impact from "Industry 4.0" technologies, the other supply chain activities will remain the same. The biggest impact on the organization of the supply chain arises from Smart Data tools and Smartphone apps and hence, these will be included in the documentation of our analysis. Smart data tools require specific knowledge from the people within the organization. Leading companies will change their requirements when hiring personnel from supply chain understanding to knowhow with respect to the topics of mathematical and statistical analysis, cyber-security data science and programming of algorithms. This knowhow will be needed throughout the whole supply chain to validate the huge amount of available data and to implement Smart Data tools and analytics (Lazovic, Montenegro and Durickovic, 2014). Despite the digitalization of physical logistics processes, the delivery of a digital value proposition to the customer is considered even more strongly (Preiß, 2014). Through Smartphone Apps, it may allow a quick response with targeted advertising to ecological and social trends discussed in social networks (Ghose and Han, 2014). Even new business models can arise from this opportunity, and new customers can be reached in different markets (Shin and Choo, 2012). This connection to social networks enabled by the IoE creates an interface with multiple other devices (e.g. servers, data bases, notebooks, tablets or mobile phones) and increases the awareness concerning IT- and cyber-security issues (Krumm, 2010). Hence, closed systems which were acting independently are now connected to other devices and networking (Zhu and Kraemer, 2002). These enable the integration of people within the production, distribution and sales processes (Zhu, 2004). During the manufacturing processes not only specific machines, but whole fractions of the production facilities may

be managed using apps via a mobile device. The distribution process is already including smartphones in the process, as truck drivers can update the intra-logistic departments of the receiving companies about the most likely time of arrival (Sha, et al., 2013). The sales processes will face huge impact from smartphone apps due to ubiquitous computing and the worldwide availability of technology. Products are sold on online platforms wherever and whenever a customer wants to reach the company (Swaminathan and Tayur, 2003). A huge autonomization is to be expected for the interaction of sales people and customers in the sales departments of companies. Hence, influences of social networks may also be of high importance. Furthermore, co-operations within the logistics process can be better organized within a pre-defined network of logistics companies. This way information about the weather or the traffic status will be better communicated within a specific network (Zammuto, et al., 2007). With this analysis, we come to the following hypothesis: With respect to the people-driven changes to the organization, the biggest impact is to be expected for the sales activity in the supply chain from the usage of Smartphone Apps and Smart Data tools.

6 Summary

Based on a structured literature review, we were able to understand that current research with respect to the term “Industry 4.0” is limited to specific, qualitative and quantitative analysis of technologies and their implementation within the company’s value chain. We first stated a definition for the term “Industry 4.0” based on the characteristic features digitalization, autonomization, network-collaboration, socializing, modularization, transparency and mobility. This was the basis for an additional analysis, which contributed to the research by the creation of a mind-map, including significantly important technologies and concepts discussed within the relevant literature. The respective management of companies from all industries can apply the method used in this paper to identify only relevant technologies with respect to their own supply chain. We have analyzed all technologies and concepts given in the mind-map with respect to the following question: Does the technology/ concept contribute or enable product or process innovations within the organization according to the identified characteristic features of “Industry 4.0”? We came to the conclusion that in total, 15 out of 49 identified technologies and concepts are of high importance. We furthermore contributed to the research by developing and applying a management-model that provides a holistic management-perspective on challenges and potentials arising from the implementation of “Industry 4.0” technologies within the organization. This model combines two theories: The theory of organizational change by LEAVITT and the supply chain activities model by MEYR and WAGNER. In the end, we came up with three interesting hypotheses with respect to organizational change

driven by the interdependent categories of structure, technology and people. The biggest impact from the "Industry 4.0" technologies and concepts is to be expected from a technological view especially for the procurement, production and distribution activities in the supply chain. The organization of the supply from a technological view will mainly change due to the implementation of BI-technologies, Smartphone Apps, AIDC- and RFID-technologies and the miniaturization of electronics. However, structural changes to the organization are to be expected mainly in manufacturing processes. Impacting technologies are the M2M-communication, and Smart Factory including Smart Logistics. With the combined implementation of Smartphone Apps and Smart Data tools, the interaction of people within the supply chain will face a huge impact in the sales departments of companies, where the customer can be integrated and organizational borders are eliminated.

As this analysis was performed based purely on the results of the structured literature review, a quantitative analysis to validate the results must be performed in future research and to confirm the hypotheses. Furthermore, the summarizing model in chapter 5 does not weigh the factors with which the specific challenges or potentials are operationalized in the framework. In future analyses, the importance of specific challenges and potentials has to be analyzed and validated in conjunction with experts in respective interviews.

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