INDUSTRY 4.0-INDUCED CHANGE FACTORS AND THE ROLE OF ORGANIZATIONAL AGILITY

Research paper

Matthiae, Marc, University of Cologne, Cologne, Germany, marcmatthiae@googlemail.com

Richter, Janek, University of Cologne, Cologne, Germany, janek.richter@wiso.uni-koeln.de

Abstract

The technological advancements in the manufacturing sector confront organizations with the convergence of industrial production and information and communication technologies. The industry is supposed to realize manufacturing of individual products while maintaining economic conditions of mass production. To react to this changing environment, government and industry initiatives have been announced worldwide. Due to international integration and export-orientation of the German economy, Industry 4.0 by the German Federal Government can be considered representative for a global phenomenon of change and disruption. A vital capability to develop in such uncertain and turbulent environments is organizational agility that is defined as the ability of firms to sense environmental change and respond readily. Although well-established consulting agencies already regard organizational agility as a key ability for Industry 4.0, no systematic scientific evidence for this assertion exists. We therefore seek to answer how organizational agility can empower manufacturing companies to manage the change induced by Industry 4.0. We conduct an extensive systematic literature review, examining Industry 4.0-induced changes categorized by change factors from literature. For each category, we examine facets of organizational agility and show how companies can manage change. We discuss our results and provide implications for research and practice.

Keywords: Organizational Agility, Industry 4.0, Change Factors, Systematic Literature Review.

1 Introduction

The technological advancements in the manufacturing sector are ushering in a fourth industrial revolution (Hermann et al., 2016; Lasi et al., 2014; Liao et al., 2017). This industrial revolution is characterized by "the combination of Internet technologies and future-oriented technologies in the field of smart objects (machines and products)" (Lasi et al., 2014, p. 239) and "the convergence of industrial production and information and communication technologies" (Hermann et al., 2016, p. 3928). The benefit of connecting machines, products and internet technologies "is supposed to realize the manufacturing of individual products in a batch size of one while maintaining the economic conditions of mass production" (Lasi et al., 2014, p. 239). "Governments and industries worldwide have noticed this trend and acted to benefit from what this new industrial revolution wave could provide" (Liao et al., 2017, p. 3609). The German federal government announced *Industry 4.0*, the term that is generally used as a synonym for this fourth industrial revolution in the German literature, as one of the key initiatives of its high-tech strategy (Federal Ministry of Education and Research, 2014). The initiative is of very high importance for the German economy, as the manufacturing industry provides over 5 million jobs (Statistisches Bundesamt, 2016) and over 25% of the GDP (Statistisches Bundesamt, 2017). Worldwide, other governments have also noticed the need for a revolution of the manufacturing sector and initiated similar projects – e.g., *Advanced Manufacturing*, United States (Rafael et al., 2014), *La Nouvelle France Industrielle,* France (Conseil national de l'industrie, 2013). We argue that the case of Industry 4.0 can be considered representative for a global phenomenon due to the international integration and export-orientation of the German economy.

Industry 4.0 has been shown to represent a disruptive change for the manufacturing sector (Bechtold et al., 2014; Kagermann et al., 2013; Schmidt et al., 2015). As many countries are engaging in this initiative simultaneously, the pressure for the manufacturing sectors in different countries to successfully manage this change is rapidly increasing. Each individual company needs to evaluate its own preparedness for this endeavour to be able to react timely. Although Industry 4.0 is currently prevalent in almost every industry-related fair, conference, or call for public-funded projects, it remains unclear which organization-wide consequences it induces (Drath and Horch, 2014). A vital capability to develop in such uncertain and turbulent environments is organizational agility, which is generally associated with a firm's ability to manage change and is defined as "the ability of firms to sense environmental change and respond readily" (Overby et al., 2006, p. 121). The focus of this paper therefore is to answer the research question: *How can organizational agility empower manufacturing companies to manage the change potential of Industry 4.0?*

Many well-established consulting agencies already regard organizational agility as a key ability for Industry 4.0 (Bechtold et al., 2014; Wee et al., 2015). However, there exists no scientific evidence for this assertion. To support the endeavour of the manufacturing sector to stay competitive in a changing environment, we argue that researchers should investigate whether organizational agility is in fact a key ability in the context of Industry 4.0. This work is a first step in this direction. It provides practitioners with an idea of the potential implications and which role organizational agility plays in this context.

To answer our research question, we analyse the changes introduced by Industry 4.0 to the business environment of manufacturing companies. We then exhibit how different facets of organizational agility can support manufacturing companies to handle these changes. For this purpose, we conduct an extensive systematic literature review, examining the changes that are commonly associated with Industry 4.0 in the current state of literature. We categorize these changes based on the work by van Oosterhout et al. (2006), who investigated change factors that require organizational agility. Finally, for each of these categories we exhibit evidence from the literature how the facets of organizational agility can enable companies to handle the specific requirements of these change clusters.

The rest of the paper is structured as follows. In the next section, we present the theoretical background on Industry 4.0 and organizational agility as well as the interrelatedness of both concepts in previous literature. The third section comprises our research method, followed by our results in the fourth section.

We discuss our results, limitations of our research and potential fields for future research in the fifth section. In the final section, we conclude our paper.

2 Theoretical Background

2.1 Industry 4.0

"The term *Industry 4.0* was established ex ante for a planned *4th industrial revolution*, the term being a reminiscence of software versioning" (Lasi et al., 2014, p. 239). In the English literature terms like *4th industrial revolution*, *industrial internet* and *smart factory* are used synonymously for this term, as the term Industry 4.0 is not common outside of the German-speaking area. There exists no unique definition for Industry 4.0, but it "collectively refers to a wide range of current concepts, whose […] precise distinction is not possible in individual cases" (Lasi et al., 2014, p. 240). Therefore, this paper uses the definition that is most widely accepted in the current literature. The core element of Industry 4.0, is the introduction of cyber-physical systems and the Internet of Things in the manufacturing industry (Spath et al., 2013).

Cyber-physical systems are defined as "integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" (Lee, 2008, p. 1). In general, a cyber-physical system consists of three levels. The physical objects (e.g., production machines or warehousing systems), a virtual data representation of the mentioned physical objects in a network infrastructure, and the services that are based on the available data concerning the physical objects (Drath and Horch, 2014).

"The internet of things refers to uniquely addressable objects and their virtual representations in an Internet-like structure. Such objects may link to information about them, or may transmit real-time sensor data about their state or other useful properties associated with the object" (Aggarwal et al., 2013, p. 384). For example, a product running through a production line could be equipped with a Radio-Frequency Identification (RFID) tag, containing all the information that is needed in the production process. The product would be uniquely identifiable and could control the individual stages of its production semi-autonomously (Kagermann et al., 2013).

Introducing cyber-physical systems and the Internet of Things in manufacturing will lead to "the emergence of dynamic, real-time optimised, self-organising value chains" (Kagermann et al., 2013, p. 20) that will facilitate numerous enhancements. Examples for this enhancements are on demand individualization and an increased resource efficiency (Lasi et al., 2014).

2.2 Organizational agility

In changing environments, organizational agility enables companies "to operate profitably […] by producing high-quality, high-performance, customer-configured goods and services" (Tsourveloudis and Valavanis, 2002, p. 330). Besides organizational agility, the terms *enterprise agility* and *agility* are used to represent this ability in the information systems literature. These terms are considered as synonyms for organizational agility and will not be further distinguished. Extant literature defines organizational agility as the ability of firms "to sense environmental change and respond readily. As such, enterprise agility consists of two components: *sensing* and *responding*" (Overby et al., 2006, p. 121). Sensing and responding are highly interrelated and in episodes of agile activities they are often intertwined in a complex manner and difficult to distinguish from each other. Thus, our working definition for organizational agility is the ability of a firm to quickly cope with unpredictable external and internal changes in order to survive unprecedented threats from the business environment, and to take advantage of changes as opportunities (Sharifi and Zhang, 1999). This broad definition helps to cover a likewise broad context of possible organizational implications.

Instead of distinguishing between the sensing and responding component, organizational agility can be categorized along the various areas of an organization's business. These different views of organizational agility can be described as facets, as illustrated in Table 1.

Facet	References
Customer agility	Sambamurthy et al. (2003)
Market capitalizing agility	Lu and Ramamurthy (2011); Panda and Rath (2016)
Operational (adjustment) agility	Chen et al. (2014); Lu and Ramamurthy (2011); Panda and Rath (2016); Sambamurthy et al. (2003)
Partnering agility	Sambamurthy et al. (2003)
Workforce agility	Breu et al. (2002)

Table 1 – Facets of organizational agility

The first facet we distinguish is *customer agility*. Sambamurthy et al. (2003) describe it as the ability of firms to use their customers as a source of market intelligence and innovation ideas. The customer is believed to be a cocreator in the development and design of innovative products and services.

To address customers' demands, firms also need *market capitalizing agility*, which is sometimes referred to as *market responsive agility* (Panda and Rath, 2016). While customer agility addresses a firm's ability to sense customer needs, this form of agility describes the ability to swiftly respond to and capitalize on changing requirements by continuously monitoring and quickly improving their products and services (Lu and Ramamurthy, 2011). Furthermore, market capitalizing agility also incorporates the capability to react to changing competitor's strategy (Panda and Rath, 2016).

The third facet described in the current literature is *operational (adjustment) agility*. While the first two facets mainly address the adjustment of products and services delivered to the market, this facet emphasizes the ability of adjusting internal business processes to cope with changing market requirements (Lu and Ramamurthy, 2011). In addition, authors argue that this ability enables firms to effectively deploy new IT solutions (Chen et al., 2014; Panda and Rath, 2016) .

The facets described so far primarily address intra-organizational resources, assets, and capabilities. When required knowledge and competencies for a certain task are not available inside the firm, it needs to leverage assets, knowledge, and competencies of its partners such as suppliers, distributors, contract manufacturers, and logistics providers (Venkatraman and Henderson, 1998). This ability is referred to as *partnering agility* (Sambamurthy et al., 2003). It has been shown that firms possessing partnering agility exhibit superior responsiveness and performance in turbulent business environments (Zaheer and Zaheer, 1997).

The need for agility in the business areas described so far put pressure on a firm's employees, especially on managers and non-production workers. The ability of employees to deal with this pressure and enable the company to realise agility is called *workforce agility* (Breu et al., 2002). This concept incorporates a variety of attributes of employees that promote the establishment of an agile company, such as employees' responsiveness to changing customer needs and market conditions or their speed to develop skills and competencies (Breu et al., 2002).

2.3 Industry 4.0 and organizational agility

Several authors investigated change factors that lead to an increased need for organizational agility (Sharifi and Zhang, 1999; van Oosterhout et al., 2006). The most comprehensive and recent view is provided by van Oosterhout et al. (2006) and thus will be used in this paper. They identified six categories of change factors that require organizational agility, namely, *social/legal*, *business network*, *competitive environment*, *customer needs*, *technology* and *internal* (van Oosterhout et al., 2006). *Social/legal* factors are characterized as changes to the workplace expectations or legal/political pressures (Sharifi and Zhang, 1999). Changes to the *business network* are attributed to the emergence of new market participants through mergers or new entrants (van Oosterhout et al., 2006). Additionally, they are characterized by changes in the collaboration between market participants (van Oosterhout et al., 2006). A changing *competitive environment* is attributed to an increasing responsiveness of competitors to changes or a rapidly changing market (Sharifi and Zhang, 1999). Corresponding to this is an increased rate of change in product variations and product lifetime shrinkage (van Oosterhout et al., 2006). Altering *customer needs* are reflected by an increasing demand for customized products and a need for quicker delivery time and time to market (Sharifi and Zhang, 1999). *Technological* change factors include the introduction of new software and the inclusion of information technology (IT) in new hard technologies (Sharifi and Zhang, 1999). Additionally, the emergence of technologies that enable the connection to partners' information systems is regarded as a change factor, which requires organizational agility (van Oosterhout et al., 2006). *Internal* changes appear mainly as a "restructuring of internal IT systems and support" (van Oosterhout et al., 2006, p. 133) and changes to the internal business processes.

The transition to Industry 4.0 will be unpredictable as the specific effects of the change for companies and society are uncertain (Drath and Horch, 2014) and the organizational implications are unpredictable (Hofmann and Rüsch, 2017). Additionally, it induces numerous changes in manufacturing systems that will not only have technological but likewise versatile organizational implications (Lasi et al., 2014). However, it remains unclear if and how the implications of Industry 4.0 correlate with the categories of change factors that are associated with a need for organizational agility.

Several articles on specific implications of Industry 4.0 have found its way in peer-reviewed quality outlets by now (e.g., Brettel et al., 2014; Gölzer et al., 2015; Lasi et al., 2014). By analysing this literature with respect to the change categories provided by van Oosterhout et al. (2006) we will show, how implications of Industry 4.0 correspond to the change factors that call for organizational agility.

3 Research Approach

3.1 Data collection

In the following, we present our approach to collect the required data to answer our research question. We follow the systematic approach for literature reviews proposed by Webster and Watson (2002). In the first step, articles are searched covering at least one of the terms that are generally associated with Industry 4.0. The parameters of this search are depicted in Table 2.

Parameter	**Value**
Title or Keywords of the article contain	*Industry 4.0* or *Industrie 4.0* or *smart factory* or *industrial internet* or *4th industrial revolution* or *fourth industrial revolution*
Type	Journal article or conference paper
Quality	VHB-JOURQUAL 3 (information systems) ranking A - D

Table 2 - Inclusion criteria for the base literature search

Articles are included if one of the terms *Industry 4.0*, *Industrie 4.0*, *smart factory*, *industrial internet*, *4th industrial revolution* or *fourth industrial revolution* is contained in the title or the keywords of the article. The abstract of the articles is not incorporated as it was found that a substantial number of articles mention Industry 4.0 in the abstract, but do not actually deal with the concept. Likewise, the terms *cyber-physical systems* and *Internet of Things* are excluded from the search as they are connected to many research areas that are not explicitly related to Industry 4.0 and would thus yield a considerable number of false positives.

To ensure a reasonable quality of the identified journal articles, the VHB-JOURQUAL 3 ranking for information systems is used (VHB, 2016). As the initiative Industry 4.0 originated in Germany, we rely on this German-based scientific journal and conference ranking to achieve a high relevance of results. Only journals that are part of the ranking categories A+, which corresponds to "outstanding, world's leading scientific journals" (VHB, 2016), to D, which corresponds to "scientific journals" (VHB, 2016), are used for the further analysis. A total of 89 outlets are listed in these categories (a comprehensive list can be found in Table 5 in the Appendix). Accounting for the interdisciplinary character of the research question, we focus on information systems. IT-enabled organizational agility is a topic that is mainly discussed in the information systems literature. Industry 4.0 on the other hand is a topic that is associated with many research areas like information systems, engineering and production management. However, to capture the relationship of both concepts we conclude that an interdisciplinary area of research as information systems is the most suited for our likewise interdisciplinary research question.

The search yields a total of eight journal articles, which are used as the base literature for the further search operations. These articles are studied to exclude any article that is not related to the topic of this paper. However, all eight articles contain relevant information and no article is excluded.

In the next step, a backward search is performed (i.e., going backward in time). Journal articles that are cited by the base articles are collected and analysed (cf. Webster and Watson, 2002). In total, 339 unique articles are cited by the eight articles in the base literature. Again, certain criteria are used to define which articles should be included and excluded from the further analysis. These criteria are shown in Table 3.

Firstly, all sources that are not published in one of the journals in the VHB-JOURQUAL 3 ranking categories A to D are excluded. The remaining articles are analysed and articles are removed, which do not clearly reference any of the concepts discussed in this paper. In the next step, the articles from the previous steps are used for the forward search. In this search, articles are collected that cite at least one of the articles found in the previous steps. Again, these articles are included in the literature if they fulfil the requirements depicted in Table 3. The backward and forward search are repeated if new articles are found that match the mentioned criteria. These search operations yield a total of 19 articles.

Parameter	**Value**
Type	Journal article or conference paper
Quality	VHB-JOURQUAL 3 (information systems) ranking A - D
Content	Related to the topic of this paper

Table 3 Inclusion criteria for the backward and forward literature search

In addition to this systematic approach, we use the results of an extensive literature review on an Industry 4.0 research agenda by Liao et al. (2017). Their literature review accurately analyses the current literature and explicitly includes practice-oriented articles to give a holistic view on the current state of research on Industry 4.0. Four articles met our criteria and are explicitly mentioned as being the top cited articles in the field of Industry 4.0 (Liao et al., 2017) are added to the set of articles increasing the number of potentially relevant articles to 23.

3.2 Data analysis

In accordance with Webster and Watson (2002), this paper uses a concept-centric approach. On the basis of the change factors requiring organizational agility identified by van Oosterhout et al. (2006) a concept matrix is constructed that is used to categorize the findings in the analysed literature.

The articles collected in Section 3.1 are analysed and categorised based on the provided change factors. The results of this analysis can be seen in Section 4. A focus is put on papers clearly referencing unpredictable or uncertain changes that are induced by Industry 4.0.

During the data analysis, further articles are excluded if they do not pertain to the concept Industry 4.0 and its implications for internal and environmental change of organizations within the manufacturing industry. Through this procedure, eight articles are excluded leading to a total of 15 articles.

4 Results

Table 4 provides an overview of change factors requiring agility in the analysed literature. In the following we present how each factor results in a set of environmental and internal implications in the context of Industry 4.0.

	Reference	Type of research	Change factors requiring organizational agility					
			Social/Legal	*Business Network*	*Competitive Environment*	*Customer Needs*	*Internal*	*Technology*
1	Barata and Cunha (2017)	Conceptual		x				x
2	Brettel et al. (2014)	Conceptual	x	x		x	x	x
3	Cupek et al. (2016)	Empirical						x
4	Drath and Horch (2014)	Conceptual	x				x	x
5	Francalanza et al. (2017)	Empirical					x	x
6	Gölzer et al. (2015)	Conceptual		x			x	x
7	Hermann et al. (2016)	Conceptual	x				x	x
8	Kagermann et al. (2013)	Conceptual	x	x	x	x	x	x
9	Lasi et al. (2014)	Conceptual	x	x	x	x		
10	Lee et al. (2014)	Conceptual					x	
11	Leyh et al. (2016)	Conceptual		x				
12	Morisse and Prigge (2017)	Conceptual	x	x			x	x
13	Niesen et al. (2016)	Conceptual	x				x	x
14	Oesterreich and Teuteberg (2016)	Conceptual	x	x	x	x	x	x
15	Thramboulidis and Christoulakis (2016)	Empirical (secondary data)						x

Table 4 Results of the literature analysis

4.1 Social / Legal

One result of Industry 4.0 will be the emergence of new social infrastructures in the workplace (Kagermann et al., 2013). The self-controlling nature of cyber-physical systems will alter the role of employees from workers towards coordinators and problem-solvers in case of unforeseen events (Brettel et al., 2014). Through the decentralization of decisions, the responsibility of individual employees will be increased significantly (Hermann et al., 2016). Both workers and managers will be required to become more flexible and adaptable with a broader range of knowledge (Drath and Horch, 2014; Morisse and Prigge, 2017). In order to enable existing employees to execute new tasks it will be necessary to implement appropriate training strategies (Hermann et al., 2016). Furthermore, due to the increasing complexity and the decentralization of decisions in the supply chain, employees need to be supported by technical assistance systems that should be designed to follow the needs of the employee instead of the reverse (Hermann et al., 2016; Lasi et al., 2014). On the other hand, the place of work will be increasingly decoupled from the physical location of the worker (Kagermann et al., 2013), promoting a better work-life balance (Kagermann et al., 2013).

The implications discussed so far reflect the increasing need for agility in the workforce of manufacturing firms. The demand for employees to swiftly develop new IT and business competencies and their empowerment for independent decision making are not novel and have been accurately addressed in the work on workforce agility by Breu et al. (2002). This facet of organizational agility is therefore highly suited to enable manufacturing firms to handle the social changes induced by Industry 4.0.

In addition to the social change potential, the new manufacturing processes associated with Industry 4.0 will find themselves confronted with several regulatory challenges including the protection of corporate data, the clarification of liability and the handling of personal data (Kagermann et al., 2013). The protection of corporate and personal data is becoming an issue of greater importance, not only in case of intentional intrusion into corporate networks. Due to the establishment of networks of cyber-physical systems across organizational boarders the volume of exchanged corporate information will rise significantly (Gölzer et al., 2015). In conjunction with other data this could provide competitors with highly sensitive information that might, for example, lead them to gain insight into the firm´s business strategies (Kagermann et al., 2013; Oesterreich and Teuteberg, 2016). The liability issue is concerned with the case, in which the recipient of corporate data fails to implement adequate IT security measures and is compromised. In this case, contractual clauses have to be added, which stipulate the penalties in the event of non-compliance (Kagermann et al., 2013). We do not see a good fit between this change factor and the presented facets of agility although it can be argued that a combination of several facets plays a significant role in dealing with changes concerning legal and security aspects.

4.2 Business network

Horizontal integration, that is, the integration of IT systems, processes and data flows between different companies, is one of the key features of Industry 4.0 (Brettel et al., 2014; Kagermann et al., 2013; Oesterreich and Teuteberg, 2016). Industry 4.0 will lead to the establishment of value networks, in which many companies are coupled through the networking capabilities provided by cyber-physical systems production systems, potentially connecting all stages of the supply chain (Lasi et al., 2014; Leyh et al., 2016). The value networks are geared towards meeting individual, last-minute customer requirements and will enable companies to use manufacturing capabilities of other companies as a service, without the need for further investments (Kagermann et al., 2013; Lasi et al., 2014). In addition, within the value networks, risks can be balanced and the combined resources expand the range of market opportunities, especially for small and medium enterprises with limited resources (Brettel et al., 2014). One of the prerequisites for the establishment of value networks is the availability of product and process data throughout the entire network, across factory and even company borders (Brettel et al., 2014). To ensure this availability, companies must provide appropriate information and communication infrastructures (Gölzer et al., 2015; Leyh et al., 2016). Additionally, they will have to be able to dynamically integrate their systems with several other partners and to change their business processes accordingly (Brettel et al., 2014).

As addressed in section 2.2 a facet of organizational agility is partnering agility, that is, the ability of a firm to leverage capabilities from partners in their business network (Sambamurthy et al., 2003; Zhang and Sharifi, 2000). Manufacturing companies that achieve partnering agility are more likely to meet implications on business network in Industry 4.0. Partnering agility is of particular importance in turbulent environments (Zaheer and Zaheer, 1997) such as created by Industry 4.0. Thus, firms possessing this capability will likely be the ones that excel.

4.3 Competitive environment

Only one of the 15 articles explicitly mentions the possible threat of the entry of new players through Industry 4.0. Lasi et al. (2014) state that new market participants will enter the manufacturing market that do not necessarily replace existing companies but constitute entirely new types of enterprises and adopt new specific roles within the manufacturing process.

However, 50 percent of the articles indicate that the introduction of Industry 4.0 will lead to novel business models. On the one hand, Industry 4.0 "will require business models that will primarily be implemented by what could be a highly dynamic network of businesses rather than by a single company" (Kagermann et al., 2013, p. 22). These new business models are necessary to facilitate new, more customer-centric value propositions, for example, through the emergence of on demand individualization (Lasi et al., 2014). Established manufacturing companies must reevaluate their business models as it will be important to offer products that are not only highly customized, but also superior in quality and competitive in price (Brettel et al., 2014). These business models can be realized through the collaboration of existing manufacturing companies. However, through specialization, new market participants will offer niche products and services more cost-effective, fostering the competition in certain market segments. New business models will emerge that adopt entirely different roles within the manufacturing process. "For instance it is possible that, comparable to brokers and clearing-points in the branch of financial services, analogue types of enterprises will also appear within the industry" (Lasi et al., 2014, p. 242). In conclusion, through the introduction of Industry 4.0 manufacturing companies will need the ability to dynamically integrate new market participants in their value chains and possibly re-evaluate their own business model.

The facet of market capitalizing agility represents a firm's ability to capitalize on changing market conditions and swiftly respond to shifting strategies of competitors. Therefore, we argue that companies that master this facet of organizational agility are the ones that will be more likely to capitalize on the novel business models and the competitive environment induced by Industry 4.0. Research has shown that the abilities included in this facet of agility are associated with high firm performance, particularly in volatile environments (Sambamurthy et al., 2003; Tallon and Pinsonneault, 2011).

4.4 Customer needs

The implementation of Industry 4.0 is supposed to allow individual, customer-specific criteria to be included just in time across the whole value chain (Kagermann et al., 2013). In the final stage, the vision for an Industry 4.0 facility is to "realize the manufacturing of individual products in a batch size of one while maintaining the economic conditions of mass production" (Lasi et al., 2014, p. 239). The integration of the customer's intelligence will enable the customer to become an active participant throughout the whole supply chain and therefore an important part of the mentioned value networks (Lasi et al., 2014). For manufacturing companies, the dynamic inclusion of changing customer requirements across the whole value chain will require them to create agile organizational structures that incorporate the implications discussed in Section 4.2 and especially Section 4.5. However, customer needs are not actually changing through Industry 4.0. Instead, the already existing demand for individualization through mass customization is realized (Kagermann et al., 2013; Lasi et al., 2014). The specific needs of customers possibly change even at a faster pace while being met by mass customization. Therefore, it seems appropriate to consider that companies with higher capabilities, relative to their competitors, for the sensing and incorporation of customer needs in its production to be more successful to meet these requirements.

The ability to react to changing customer preferences on a strategic and operational level is an integral part of organizational agility (Overby et al., 2006; van Oosterhout et al., 2006). Customer involvement and integration is a vital ability for manufacturing companies. We believe that companies that exhibit the capability – referred to as customer agility – in their current production processes will continue to do so in the Industry 4.0 environment and will be the ones succeeding.

4.5 Internal

Internal (i.e., intra-organizational) implications of Industry 4.0 are mainly associated with changes to the internal IT systems and the business processes of an organization. One major aspect of Industry 4.0

is the establishment of intelligent products and production processes (Brettel et al., 2014). The introduction of cyber-physical systems enable production processes to become intelligent, meaning that they are self-evolvable, self-reconfigurable, self-tuning and self-diagnosing (Francalanza et al., 2017). On the other hand, products become intelligent by being able to control the individual stages of their production process semi-autonomously and across company borders (Gölzer et al., 2015; Lasi et al., 2014). To incorporate the intelligent production processes and products in the operational organization, a change from product- to service-orientation is expected (Brettel et al., 2014; Lasi et al., 2014).

By an increasing integration and openness of manufacturing systems cyber security, that is, the prevention of unauthorized access to production systems and production data, is becoming a topic of increased interest (Drath and Horch, 2014; Hermann et al., 2016; Morisse and Prigge, 2017). Integrating the information and communication technology capabilities into established manufacturing plants creates new danger potentials that are currently not reflected in concepts for industrial risk assessments (Niesen et al., 2016). Industry 4.0 will potentially lever the number of harmful attacks on production facilities (Hermann et al., 2016) and manufacturing companies need to address this issue to prevent environmental and economic damage as well as harm to humans (Drath and Horch, 2014).

Another topic that is associated with internal changes is the project and change management methodologies, which are needed for the introduction of Industry 4.0. There exist several works that propose maturity models for manufacturing companies with respect to Industry 4.0 (Barata and Cunha, 2017; Leyh et al., 2016; Morisse and Prigge, 2017). However, only Barata and Cunha (2017) propose a framework for the enhancement of the maturity.

Firms that possess the facet of operational agility can rapidly redesign existing processes and create new processes for exploiting dynamic marketplace conditions (Sambamurthy et al., 2003). Therefore, firms that possess operational agility are more likely to be capable of dealing with constant business process changes that are introduced in the era of Industry 4.0.

4.6 Technology

Industry 4.0 embodies an abundance of technological innovations which include cyber-physical systems, Radio-Frequency Identification and the Internet of Things (Oesterreich and Teuteberg, 2016). The ongoing integration of these technical innovations in industrial environments will make extensive amounts of real-time data from various production resources available for further analysis (Gölzer et al., 2015; Niesen et al., 2016). The processing of this high volume of data into useful information will be the key for sustainable innovation within an Industry 4.0 factory (Lee et al., 2014).

Another important aspect is the end-to-end integration of business processes including engineering workflows and services using cyber-physical systems (Kagermann et al., 2013). The spatial distribution of processes across company boarders will demand a comprehensive integration of data and standardized semantics and interfaces to enable efficient communication and data exchange across the value chain (Gölzer et al., 2015; Kagermann et al., 2013; Thramboulidis and Christoulakis, 2016). There exist several works that address this issue and propose different methodologies for a common data exchange and standardized interfaces (Cupek et al., 2016; Thramboulidis and Christoulakis, 2016). However, a commonly agreed framework has not yet been established.

Vertical integration, that is, the creation of flexible and reconfigurable manufacturing systems through the usage of cyber-physical systems within a company, is one of the key topics for Industry 4.0 factories. In contrast to horizontal integration, that is, the close collaboration between multiple enterprises in a value network, vertical integration denotes an increasing information exchange and collaboration among different levels of hierarchy within an enterprise (Niesen et al., 2016). This integration is a mandatory requirement for the cross-functional collaboration between product development, manufacturing, logistics and sales, resulting in a *smart* manufacturing environment (Oesterreich and Teuteberg, 2016). To achieve horizontal and vertical integration simultaneously, the IT architecture has to become service-oriented (Kagermann et al., 2013). This assumption is consistent with the service orientation in business processes mentioned in Section 4.5.

The facet of operational agility incorporates the ability of firms to integrate processes and IT systems and rapidly supply comprehensive up-to-date information (Sambamurthy et al., 2003; Zhang and Sharifi, 2000). Operational agility has also been shown to fully moderate the impact of IT capabilities on a firm's performance (Chen et al., 2014). Therefore, companies possessing this facet of organisational agility are more competent in the integration of new IT solutions and presumably will be more successful in the environment created by Industry 4.0.

5 Summary and Discussion

The main goal of this paper was to answer the research question: *How can organizational agility empower manufacturing companies to manage the change potential of Industry 4.0?* Figure 1 summarizes the Industry 4.0-induced changes categorized by change factors and mapped to the facets of organizational agility that enable companies to handle these change factors.

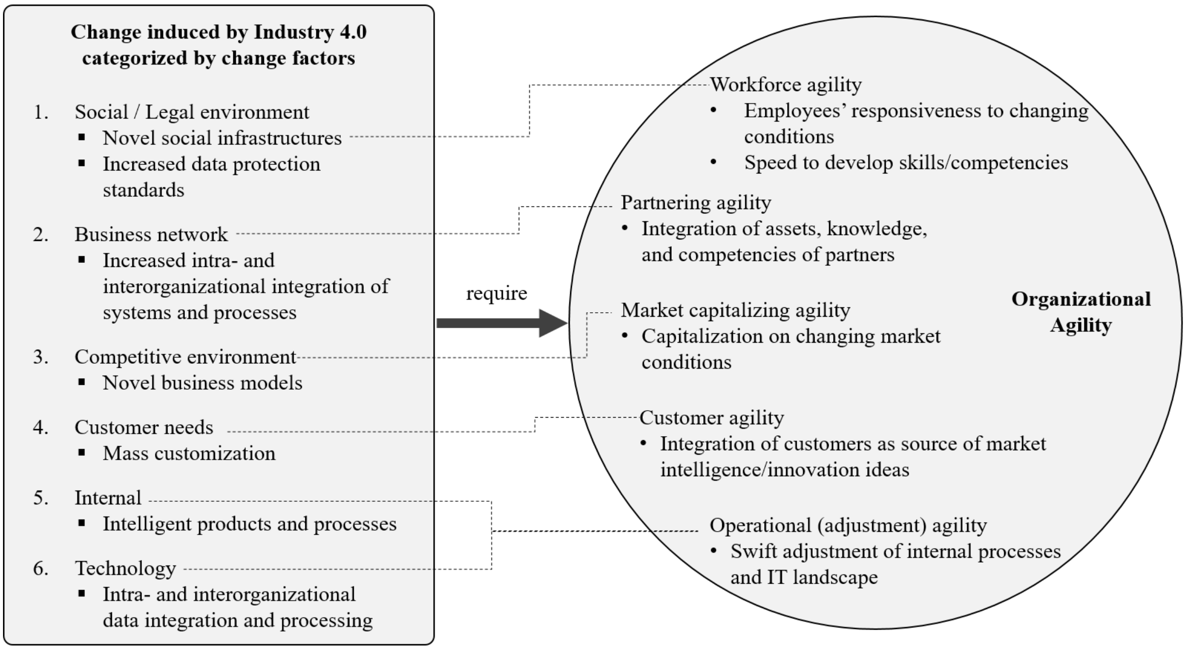

Figure 1 Change factors induced by Industry 4.0 that require organizational agility

Our results show that Industry 4.0 poses several change potentials for the manufacturing industry that can be associated with facets of organizational agility. However, only one of the identified academic articles, namely the work of Morisse and Prigge (2017), mentions organizational agility as an important ability in the context of Industry 4.0. A possible reason for the missing attention in the academic literature is the fact that Industry 4.0 "is still in the future" (Drath and Horch, 2014, p. 58) and therefore much of the research on the specific requirements remains to be done. This hypothesis is supported by the fact that most of the cited references in the academic literature on Industry 4.0 (i.e., Kagermann et al., 2013) explicitly call for more research on the topic.

To contribute to this research, we examined possible implications of Industry 4.0 for the business environment of manufacturing companies. By showing possible connections between concrete implications and facets of organizational agility, we present a potential approach of organizational requirements that manufacturing companies face in the context of Industry 4.0. The categorisation into groups of change factors and corresponding facets of organizational agility provides practitioners with a preliminary framework and constitutes an overview of possible avenues for specific situations to achieve organizational agility. For researchers, our research connects two previously independent literature streams (i.e., those on organizational agility and Industry 4.0) and shows how Industry 4.0 challenges can be addressed by insights from extant agility research. We also identified blind spots such as the induced changes concerning legal and security issues that the agility literature has so far not explicitly focused on. This poses a valuable avenue for future research.

Missing knowledge on the specific requirements of Industry 4.0 limits the significance of this work. Although most of the identified changes that Industry 4.0 induces can be associated with the ability of organizational agility, it is unclear if organizational agility is in fact a *key* ability for the initiative. This is underscored by the fact that research on Industry 4.0 is still in its infancy. Thus, the resulting small body of literature is predominantly conceptual in character. Another limitation of this work arises through the selection of quality criteria used in the data collection. The focus on high quality academic articles implies that practitioner-oriented work comprising industry cases is not included in the data. The focus on information systems literature may have led to a lack of important insights from other fields such as operations research and engineering. However, we argue that the interdisciplinary character of information systems reduces this limitation. Furthermore, we observed a broad range of Industry 4.0 change factors in the analysed literature.

Future research on organizational requirements in the context of Industry 4.0 should follow the direction of this work by deriving possible organizational implications from the technological innovations. The specific organizational requirements for Industry 4.0 will be one important aspect for the success of this initiative, as reflected by the fact that several renowned consulting companies are working on the establishment of organizational frameworks for Industry 4.0 (Bechtold et al., 2014; Wee et al., 2015). However, research is lacking strong empirical evidence.

Another issue that is rarely discussed in the current literature are the societal and macroeconomic consequences of Industry 4.0. Even though it is frequently mentioned that the role of common workers is changed towards decision makers, it is not examined which consequences might be expected for the overall employment in the industry. As Industry 4.0 clearly aims for a higher resource efficiency and a reduction of human capital, this topic should be of higher importance.

6 Conclusion

With our analysis of Industry 4.0-induced change, we contribute to the understanding of how organizational agility can empower manufacturing companies to manage change in times of uncertainty and turbulence in the industry. Based on our results categorized by six established change factors in the agility literature, we provide an overview for practitioners and researchers alike. Furthermore, our results corroborate the assertion that organizational agility represents a key ability to manage change in contexts such as Industry 4.0. We therefore as well contribute to the literature stream with management-oriented focus on the phenomenon of Industry 4.0 that has been lagging behind compared to technical-oriented publications.

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Appendix

Searched Outlets sorted alphabetically
ACM Computing Reviews; ACM Computing Surveys; ACM SIGMIS Database; ACM Transactions on Computer-Human Interaction; ACM Transactions on Information Systems; ACM Transactions on Management Information Systems; Advanced Information Systems Engineering. Proceedings of the International Conference CAiSE ; AIS Transaction on Enterprise Systems; Artificial Intelligence; Australasian Journal of Information Systems (AJIS); BIT Banking and Information Technology; Business & Information Systems Engineering (BISE); Business Process Management Journal; Business Process Management Workshops; Communications of the ACM (CACM); Communications of the Association for Information Systems (CAIS); Computer Supported Cooperative Work (CSCW); Computers and Operations Research; Computers in Industry; Data & Knowledge Engineering; Decision Sciences; Decision Support Systems (DSS); Electronic Commerce Research; Electronic Commerce Research and Applications (ECRA); Electronic Markets (em); Enterprise Modelling and Information Systems Architectures (Online); e-Service Journal; European Journal of Information Systems (EJIS); Group Decision and Negotiation; HMD - Praxis der Wirtschaftsinformatik; Human-Computer Interaction; IBM Journal of Research and Development (former IBM Systems Journal); IEEE Computer; IEEE Software; IEEE Transactions on Engineering Management; IEEE Transactions on Software Engineering; IEEE Transactions on Systems, Man, and Cybernetics: Systems; Informatik-Spektrum; Information & Management; Information and Organization; Information Systems (IS); Information Systems and e-Business Management; Information Systems Frontiers; Information Systems Journal (ISJ); Information Systems Management; Information Systems Research (ISR); Information Technology and Management; INFORMS Journal on Computing (JOC); International Journal of Electronic Business; International Journal of Electronic Commerce (IJEC); International Journal of Information Management; International Journal of Information Technology & Decision Making; International Journal of Knowledge Management (IJKM); International Journal of Mobile Communications; International Journal of Service Science, Management, Engineering, and Technology (IJSSMET); International Journal on Media Management; Journal of Computational Finance; Journal of Computer-Mediated Communication (JCMC); Journal of Decision Systems; Journal of Electronic Commerce in Organizations; Journal of Electronic Commerce Research; Journal of Enterprise Information Management

Table 5 List of searched outlets from the VHB-JOURQUAL 3 (information systems) ranking.