Structuring the Anticipated Benefits of the Fourth Industrial Revolution

Completed Research

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Abstract

The digitalization of production facilities and the accompanying changes are anticipated to transform entire industries posing a fierce pressure on companies to deal with these developments regarding their information technology management. To lay the foundation for the development of corresponding business strategies, we structure benefits of Industry 4.0 through a structured literature review and categorize them using an established framework for IS benefits. Benefits for companies arise within four dimensions and concern various issues ranging from production related benefits to superordinate benefits affecting the business model. To conclude, managerial implications resulting from dependencies and the variety of benefits are presented.

Keywords

Industry 4.0, benefits framework, organizational perspective, structured analysis.

Introduction

In the recent past, there has been a tremendous hype built up around Industry 4.0. The term comprises technological developments such as Internet-of-Things (IoT), Internet-of-Services, or cyber physical systems (CPS) (Lasi et al. 2014). In this paper, we focus on CPS as a representative of Industry 4.0, the implementation of smart factory concepts and their anticipated benefits. As Industry 4.0 is a terminology particular common in Germany and in absence of a common global terminology, we explicitly include related concepts such as Industrial Internet, Smart Manufacturing, or Advanced Manufacturing that are common in English-speaking countries. In our understanding, Industry 4.0 comprises in its inner kernel the advanced digitalization of production facilities through the digital connection of smart machines and products with networked embedded systems and the extensive integration of information systems, digital services, and Internet-based technologies (Barrett et al. 2015; Schuh et al. 2014b; Zuehlke 2010). These promise great potentials and benefits for industrial applications as smart products are envisioned to self-control their manufacturing process and smart factories are anticipated to self-optimize production processes in real-time and respond context-specific to turbulences in production and to fast changing customer demands (Schuh et al. 2014b). Besides others, these capabilities increase efficiency and competitiveness as they enable the flexible production of highly customized products at costs comparable to mass production (Radziwon et al. 2014). Further, innovative digital business models like predictive maintenance or pay-per-use concepts utilize the tremendous amount of generated production and product data and enable innovative products enhanced with digital services (Lasi et al. 2014).

These developments are anticipated to deeply impact existing business strategies and success models and transform whole economies in a disruptive manner (Iansiti and Lakhani 2014). Therefore, companies in all industries face a fierce pressure to deal with the fundamental changes and rethink their strategies regarding investments in Industry 4.0 technologies to retain competitiveness (Geisberger and Broy 2015). Otherwise, increasing efficiency of competitors, market entries of non-traditional competitors, and new digital business models intensify competition and, ultimately, jeopardize companies that fail to undergo the
necessary transformation process. Accordingly, companies must not only evaluate whether to invest into Industry 4.0, but especially into which specific technologies and in which order. To come to these crucial strategic decisions in correspondence with value-based management principles, investments have to be evaluated ex-ante under consideration of involved costs, risks, and benefits (Faisst and Buhl 2005). While costs and risks have already been researched quite extensively, benefits of Industry 4.0 have not yet been investigated in a structured manner. Till date, authors only point out benefits for motivational reasons or evaluate highly specific and application-dependent benefits. To the best of our knowledge, there is no comprehensive picture of Industry 4.0 technologies and their contribution to value creation. Consequently, the evaluation of benefits remains a major obstacle as the variety and complexity of technologies and the absence of best-practices or industry standards complicate their identification and quantification. However, this would be necessary to ensure a holistic view on Industry 4.0 business strategies. To close this gap, our research focuses on benefits of Industry 4.0 and addresses the following research question:

RQ: Which benefits of Industry 4.0 are anticipated in scientific literature?

By identifying benefits based on a structured review of scientific literature and by categorizing them into a structured benefits framework, we provide a comprehensive overview of the benefits of Industry 4.0. This helps to better describe the characteristics of Industry 4.0 technologies that are associated with value creation. Further, our research represents an essential first step towards the comprehensive evaluation of smart manufacturing technologies and lays the ground for a subsequent identification and quantification of benefits. The remainder of our paper is organized as follows: We outline our methodology in Section 2. Section 3 provides a review on the investigated literature. Section 4 presents the identified benefits and a categorization of these benefits into an IS benefits framework. Section 5 contains a discussion of managerial implications, before Section 6 presents a conclusion and gives an outlook on further research.

Research Methodology

As Industry 4.0 is a quite young field of research and the body of corresponding literature on benefits of Industry 4.0 is rather limited, the aim of our research is not the synthesis of research on benefits, but a methodically sound identification of respective benefits mentioned in scientific literature. For the approach conducted in this research, the methods presented by Bandara et al. (2011), Fettke (2006), vom Brocke et al. (2009), and Webster and Watson (2002) concerning structured literature reviews in the IS field serve as a basis. Although the approaches coincide in their basic structure (e.g., all authors incorporate a literature search comprising keyword search in databases), they differ regarding their exact research procedure and purpose. Therefore, we combine the approaches and derive four steps: Subsequent to a literature search (1), relevant articles are identified (2) and analyzed (3). Afterwards, the results are structured (4).

Step 1 - Search process: Since the investigated topic is an emerging field and concerns various disciplines, a concept-centric literature search is executed (Webster and Watson 2002). To query a wide selection of journals and to include conference proceedings, we query databases listed in Table 1 with search terms for Industry 4.0 and related concepts (i.e. Industry 4.0, Internet-of-Things, or smart manufacturing) in combination with terms that ensure results with a strong association industrial applications (i.e. production, manufacturing, or factory). The keyword search is conducted in the search fields abstract, title, and keywords as this search strategy is supposed to render papers focusing on the target topic (Bandara et al. 2011). The search strategy renders a total of 177 results.

<table>
<thead>
<tr>
<th>Databases</th>
<th>ScienceDirect, EbscoHost, ProQuest, AIS eLibrary</th>
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<tbody>
<tr>
<td>Search Fields</td>
<td>Title, Abstract, Keyword</td>
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<tr>
<td>Source Types</td>
<td>Journals, Conferences</td>
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<tr>
<td>Search Terms</td>
<td>(Industry 4.0 OR Industrie 4.0 OR Internet of Things OR Industrial Internet OR Cyber Physical System OR Cyber Physical Production System OR Smart Factory OR Smart manufacturing) AND (production OR manufacturing OR factory OR Produktion OR Fabrik OR Industrie)</td>
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Table 1. Parameters of Keyword Search

Step 2 - Selection of relevant literature: As vom Brocke et al. (2009) argue, the limitation of the amount of literature by keyword search should be content-based and include analyzing titles, abstracts and full texts. Accordingly, titles of all articles are examined to exclude articles not dealing with Industry 4.0 or dealing with non-industrial applications. Further, all articles in other languages than English or German are
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excluded. Then, abstracts of the remaining articles are analyzed to select those discussing Industry 4.0. In a last step, full texts of the remaining articles are screened by examining relevance for Industry 4.0 and if benefits of Industry 4.0 are mentioned in the article. This results in 57 articles (55 in English and 2 in German) relevant for further analysis. 27 articles are published in conference proceedings from different fields like production engineering, or computer sciences. The other 30 articles were published in journals from different fields ranging from engineering and computer sciences to management sciences.

Step 3 - Analysis of relevant literature: 57 publications are analyzed for mentioned benefits of Industry 4.0. Thereby, we define benefit as an umbrella term for positive effects like opportunities, potentials, value, or improvements for companies achieved through the implementation of Industry 4.0 technologies. Thus, macro-economic effects for economies are not considered. Thus, we subsume different levels of benefits, i.e. different degrees of concretization, under one term. This approach seems reasonable as Industry 4.0 is a young and emerging field of research and, so far, the vast majority of benefits remain rather vague potentials with no empirical evidence in literature. Each benefit mentioned and the respective publication are recorded in a database resulting in an initial list of multiple benefits. After consolidating the initial list and removing doubles and highly similar benefits, we obtain a list of 365 benefits.

Step 4 - Synthesis of analysis results: There are different frameworks for structuring benefits. For instance, DeLone and McLean (1992) provide a framework with six dimensions regarding aspects of IS and Abelein et al. (2009) develop a framework consisting of technical, organizational, and strategic business dimensions. An established framework for IS benefits proposed by Anthony (1965) structures benefits into the three dimensions operational, managerial, and strategic as this allows the distinction of benefits regarding the hierarchical levels of decision-making in organizations, i.e. operational control, managerial control, and strategic planning. Since we aim to provide the basis for the analysis of individual use cases and concrete decisions, we regard Anthony’s (1965) framework as most suitable. This classification supports the differentiation of the impact of benefits and, thus, facilitates their subsequent in-detail evaluation and quantification. Numerous authors applied an extended version of Anthony’s three dimensional framework by adding the dimensions organizational and information technology (IT) infrastructure (e.g. Shang and Seddon 2000, Shang and Seddon 2002; Wang et al. 2016) as it was discovered that certain IT benefits could not (unambiguously) be clustered without them, in example organizational benefits in terms of improved focus, cohesion, learning and execution were identified (Shang and Seddon 2002). However, as we view advancements of IT as core enabler of Industry 4.0, we refrain from gathering benefits describing enhancements of IT and do not include IT infrastructure in our framework. Additionally, IT is developing at an increasingly pace, so the inclusion of corresponding benefits would impair the framework’s long-term relevance.

Each benefit is assigned to one of the four dimensions. Nevertheless, there are interdependencies between the dimensions that are addressed later in this paper. To ensure objectivity, the benefit assignment is done by two researchers separately and merged while assignment differences are discussed. In a second step, benefits within each dimension are clustered, again by two researchers separately, and matched to consolidated benefits. Finally, we obtain our benefits framework as the central artefact of our research: a structured representation of Industry 4.0 benefits. The framework is evaluated by a discussion with ten other researchers and the results of the evaluation are considered in the further development of the framework presented in Section 4.

Overview of the Investigated Literature

In the following, we give an overview on the examined scientific literature concerning Industry 4.0 from different fields of research like engineering, operations research or sustainability. Due to the innovative nature, many authors approach Industry 4.0 in a general manner, propose definitions, and discuss the state of technologies and future research and development challenges. For example, Mikusz and Csiszar (2015) develop a framework to examine characteristics and abilities of a CPS application in industrial robotics. Wang et al. (2015) outline characteristics and definitions of CPS and present advancements in CPPS to point towards research directions. Other authors focus on risks and opportunities of smart manufacturing (Banham 2015), review the term smart in relation to technology, and propose a definition for smart factories (Radziwon et al. 2014). However, due to a macro-perspective view on Industry 4.0, these approaches make only general statements on benefits of industry 4.0 in the context of new business models.
Despite these general approaches, there are publications addressing specific topics accompanying Industry 4.0 and related concepts. For example, some investigate architectures or models for the integration of CPS/CPPS in manufacturing and the realization of smart factories (Bagheri et al. 2015; Majstorovic et al. 2015). Other authors like Wright (2014) outline the effects of CPPS regarding products or focus on effects for humans in smart manufacturing environments (Dombrowski and Wagner 2014). An issue examined by several authors concerns production and process management (Denkena et al. 2014; Reischauer and Schober 2015; Seitz and Nyhuis 2015). For example, Seitz and Nyhuis (2015) present advantages of CPS for production planning, controlling, and monitoring. A different stream of literature deals with the implication for supply chains (Frazzon et al. 2015; Papazoglou et al. 2015; Veza et al. 2015). A reference architecture for smart manufacturing networks is developed by Papazoglou et al. (2015), while Veza et al. (2015) propose a management approach for smart factory networks. Laboratory research facilities are another topic discussed (Faller and Feldmüller 2015; Hummel et al. 2015; Schuh et al. 2015a; Weyer et al. 2015; Zuehlke 2010). For instance, Hummel et al. (2015) point towards the importance of learning factories for the qualification and training of professionals. Moreover, several different topics are discussed such as the collection and processing of data, data analytics, and simulations (Barthelmey et al. 2014; Lee et al. 2014; Neuböck and Schrefl 2015; Rosen et al. 2015), the development of new business models (Rudtsch et al. 2014), collaboration mechanisms (Schuh et al. 2014b; Schuh et al. 2015b), service innovations (Hertrich et al. 2015) or lean production principles (Kohlberg and Zuehlke 2015). These approaches give explicit examples for benefits, however, due to the specific research context, they are only partially applicable for the comprehensive evaluation of the strategic use of Industry 4.0.

Based on this diverse body of scientific literature, we can conclude that scientific literature mentioning benefits of Industry 4.0 and related concepts differs in focus and scope and deals with various aspects of these concepts. Despite the variety of different approaches, to the best of our knowledge, there is no structured framework that provides practitioners with a comprehensive overview of potential benefits. Therefore, we aim to contribute to this research gap by proposing a structured benefits framework to enable decision makers to identify relevant fields of actions for their digitalization strategy and to evaluate potential benefit dimensions from the realization of Industry 4.0 investments and their contribution to value creation in organizations.

### Categorizing the Benefits of Industry 4.0

<table>
<thead>
<tr>
<th>Operational</th>
<th>Managerial</th>
<th>Strategic</th>
<th>Organizational</th>
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<tbody>
<tr>
<td>Production Flexibility</td>
<td>Production Efficiency</td>
<td>Decision Making / Support</td>
<td>Business Model</td>
</tr>
<tr>
<td>Continuous Production Optimization</td>
<td>Production Quality</td>
<td>Risk Management</td>
<td>Competitiveness</td>
</tr>
<tr>
<td>Production Safety</td>
<td>Resource Efficiency</td>
<td>Financial Benefits</td>
<td>Product Innovation &amp; Improvement</td>
</tr>
<tr>
<td>Production Reliability</td>
<td>Product Development</td>
<td>Production Planning &amp; Scheduling</td>
<td>Alignment of Production with Changing Individual Customer Demands</td>
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<tr>
<td>Production Availability</td>
<td>Supply Chain Collaboration</td>
<td>Continuous Improvement</td>
<td>Sustainability</td>
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**Figure 1. Benefits framework for Industry 4.0**

In the following, we present our benefits framework for Industry 4.0 that is based on an IS benefits framework as it provides predefined dimensions for the consolidation and categorization of the extensive list of identified benefits. Further, the framework is designed for managers to support the assessment of benefits and, therefore, is appropriate for the categorization of benefits considering practitioners’ needs regarding organizational decision-making and strategy development. As mentioned in Section 2, the applied framework comprises operational, managerial, strategic, and organizational benefits. Operational benefits contain benefits concerning periodically repeated actions and improvements of practical tasks (Shang and Seddon 2002), while managerial benefits refer to benefits resulting from a better supply of information facilitating advances in the resource allocation and control, operation monitoring and support of strategic business decisions (Shang and Seddon 2002). Benefits affecting long-term planning and high-level decisions are referred to as strategic benefits (Shang and Seddon 2002). Further, organizational benefits involve overarching goals such as focus, learning, and execution within
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organizations (Shang and Seddon 2002). The benefits are allocated to one of the four dimensions. Since many benefits address same or related issues, similar benefits are consolidated and clustered within the respective dimensions. Figure 1 shows our benefits framework for Industry 4.0 comprising benefits anticipated in scientific literature. As each benefit is a condensate of several benefits from scientific literature, we provide detailed insights into related concepts of each benefit in tables 2 to 5 and indicate the number of articles within our final paper sample in which a benefit was mentioned. However, the number of articles is only informative and does not allow an assessment of the significance of a benefit.

Benefits assigned to the operational dimension of our framework are primarily production related. For instance, continuous production optimization refers to the capability of smart factories to (self-) optimize the production system or production processes. Thereby, Industry 4.0 technologies allow the optimization regarding various goals and business metrics as stated by Weyer et al. (2015) and Kolberg and Zuehlke (2015). Another concept widely discussed is production flexibility. While in some cases, flexibility is not further expanded on, in some publications it is associated to modularity and reconfigurability of production systems and processes through plug-and-play principles. Veza et al. (2015) present a different perspective, pointing towards the flexibility in terms of short-term responsiveness in case of disruptions. Further related concepts are adaptability, agility, and variability. Another aspect of production expected to benefit from Industry 4.0 is production safety. The anticipated benefits are mainly a reduction of reworking or scrap. Wright (2014) for instance states that wireless sensors can guarantee that final products are completely manufactured. Further, production reliability is supposed to benefit from Industry 4.0 including robustness, resilience, and the handling of unprecedented events enabling production systems to reduce potential human error (Banham 2015) and to autonomously improve or maintain a status by self-diagnosis technologies (Mönks et al. 2016). A special case of reliability is production availability discussed extensively in literature and referring to a reduction of downtime and a higher usability of intelligent factories.

<table>
<thead>
<tr>
<th>Benefit</th>
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<tbody>
<tr>
<td>production flexibility [24]</td>
<td>i.a. flexibility; adaptability, and reconfigurability of production systems; modularity of production modules; easing of engineering and set up; flexibility during technical modification; less time consumption during commissioning; no engineering efforts for reconfiguration; high process variability; adaptability to new product variants or production systems</td>
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<tr>
<td>continuous production optimization [26]</td>
<td>i.a. optimization of production; of production systems and processes; enhanced equipment efficiency; compensation of limited manufacturing capabilities; self-optimization of production systems; enhanced production capabilities</td>
</tr>
<tr>
<td>production safety [8]</td>
<td>i.a. higher safety; safer asset utilization; reduction of safety incidents</td>
</tr>
<tr>
<td>production reliability [23]</td>
<td>i.a. high reliability; robustness; resilience; handling of unprecedented events; flexibility to respond to disruptions and failures in real-time; autonomous problem handing and reaction to maintain the system's status</td>
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<tr>
<td>production availability [4]</td>
<td>i.a. increased/high availability; reduction of machine downtime; usability of intelligent factories</td>
</tr>
<tr>
<td>production efficiency [33]</td>
<td>i.a. improved production efficiency; more efficient asset utilization; just-in-time proceeding of goods; efficient transportation; increased service efficiency; increase of throughput; faster production ramp-up; improved technical support and maintenance; improved quality control</td>
</tr>
<tr>
<td>production quality [10]</td>
<td>i.a. fewer product defects; reduction of reworking; lowering of scrap and failures; quality improvement</td>
</tr>
<tr>
<td>resource efficiency [15]</td>
<td>i.a. energy savings; less energy consumption; resource efficient production; optimal resource consumption; reduction of material and supply usage; reduction of waste; gains in material efficiency</td>
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<tr>
<td>product development [7]</td>
<td>i.a. innovative product development; accelerated development processes; flexible product development; better quality of development; reduction of number of iterations between product designers and process planners</td>
</tr>
<tr>
<td>supply chain collaboration [4]</td>
<td>i.a. increase of collaboration productivity; higher supply chain productivity; higher agility and integration of complete supply chain; improved overall performance of supply chains in terms of service-level and flexibility; increase of logistic performance</td>
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**Table 2. Operational Benefits of Industry 4.0**

Further, an increase of production safety is expected including higher safety of machines and the reduction of safety incidents. Another operational benefit is production efficiency. While some authors mention general efficiency gains in relation to production or asset utilization, others, anticipating more specifically, for instance, a promotion of just-in-time manufacturing. One concept in regard to production efficiency is a better technical support of machinery and plant equipment. Rudtsch et al. (2014) describe the concept of remote maintenance that will support maintenance processes through web-based technologies and IoT. Further operational benefits not directly affecting the shop floor are resource efficiency and product development. Resource efficiency is addressed in some cases in general, but also more specific in regard to
energy efficiency in terms of a lower energy consumption or energy savings. Similarly, general benefits regarding resources are expected to materialize through a more accurate resource deployment, which is also reflected in waste reduction and a lower overall consumption of resources. In addition to the production of products, benefits are also anticipated for product development. As Rosen et al. (2015) argue, ubiquitous connectivity will close the digitalization loop and enable optimized product design cycles. Further, Schuh et al. (2014a) state that simulation and virtualization will enable accelerated development processes. Thereby, virtualized development processes contribute to resource efficiency through reduced material usage. Contemplating a network of firms, another operational benefit is improved supply chain collaboration as higher collaboration productivity through improved information sharing and increased IS integration across company-boundaries within the eco system is one core characteristic of Industry 4.0.

Managerial benefits comprise - similar to the operational level - benefits directly related to production as well as benefits not related to production. There, the benefit production planning & scheduling subsumes the optimization of production management and planning, of maintenance scheduling, and of inventory management as well as efficient and advanced planning processes. Schuh et al. (2015b) outline that an improved cooperation within a network of firms enables improved forecasting and advanced and efficient planning processes and, thus, facilitate to counteract over-production as a result of bullwhip-effects. Further, continuous improvement enabled by increasing transparency through improved data acquisition and analysis affects production as it concerns effective and efficient process and performance improvement. For instance, Kolberg and Zuehlke (2015) elaborate on Industry 4.0 technologies and their application in regard to lean production principles and conclude that innovative automation technology is a promising topic. While benefits regarding decision making / support might concern production, they are not limited to it. Yang et al. (2016) state that real-time information about positioning and working status might assist decisions concerning production and inventory management. Schuh et al. (2015b) further argue that enabling a higher transparency within the supply chain contribute to comprehensibility and, thus, sustainability of decisions and their effects. Benefits not directly linked to production concern risk management. While Majstorovic et al. (2015) and Davis et al. (2012) address risk management without presenting more details on how Industry 4.0 is supposed to assist, Banham (2015) discusses the reduction of risk at length, arguing that overall strategic, operational and financial risks are reduced. For instance, the increased flexibility of production systems reduces both strategic risks in regard to fast changing customer demands and operational risks in regard to lengthy technical modifications, while improved product development reduces product failure risks and, thus, financial risks. Benefits concerning positive financial aspects are summarized as financial benefits resulting from various aspects like effects on the shop floor. For example, Bagheri et al. (2015) refer to significant economic potential of Industry 4.0 enhanced factories. Similar to the operational dimension, benefits regarding supply chain management also exist in the managerial dimension, for instance, in regard to shared information management, risk management or general optimization. Indeed, managerial benefits are more divers including a better handling of complexity, security for single parts of a supply chain, and a better level of information sharing.

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<th>Benefit</th>
<th>Related Concept</th>
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<tbody>
<tr>
<td>decision making / support</td>
<td>i.a. effective and efficient decision making; improved decision support; improved performance monitoring in distributed manufacturing; real-time reaction on problems in production</td>
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<tr>
<td>risk management</td>
<td>i.a. improved risk prediction, planning, and management; reduction of strategic, operational, and financial risk</td>
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<tr>
<td>financial benefits</td>
<td>i.a. economic potential; improvement of working capital; radical performance improvement</td>
</tr>
<tr>
<td>production planning &amp; scheduling</td>
<td>i.a. efficient and advanced planning process; optimization of manufacturing management, maintenance, and service scheduling; optimal production planning and inventory management; adaptive production scheduling; reduced planning costs</td>
</tr>
<tr>
<td>continuous improvement</td>
<td>i.a. effective and efficient process improvement; continuous improvement processes; enhancing existing lean production solutions and extending their applicability; improvement of overall performance and maintenance management; continuous improvement of manufacturing processes; higher quality of processes; improvement of quality of production</td>
</tr>
<tr>
<td>supply chain management</td>
<td>i.a. dynamic management of complex environments with short-lived supply chains; security for all supply chain’s elements, access to data, knowledge about demand/stock/sales/prediction of anomalies; optimization of value chain by implementation of autonomously controlled and dynamic production; solving problem of complexity in supply chains</td>
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Table 3. Managerial Benefits of Industry 4.0

Strategic benefits comprise abilities by generating new business models, enabling product improvement and innovation, and the alignment of production with changing, individual customer demands as well as
an enhancement of competitiveness and sustainability. Further, new business models become feasible. While some authors make rather general statements on new opportunities for value-creation, Veza et al. (2015) and Mikusz and Csiszar (2015) give explicit examples arguing that new business models emerge in form of complementary or additional services. According to Mikusz and Csiszar (2015), new business models facilitated by networked CPS within production facilities and the availability of real-time information are Add-On, Product as a Point of Sales, Object Self-Service, and Lock-in business models. Veza et al. (2015) state that new business models appear in the form of Manufacturing-as-a-Service, Industrial Product-Service Systems, or comparable. Regarding product innovation and improvement, benefits include the enhancement of product performance, its design, quality, and sustainability as well as additional digital services, and shorter innovation cycles. For example, Davis et al. (2012) argue that new innovative products are facilitated by increased workforce and manufacturing innovation. Another benefit is the alignment of production with changing, individual customer demands. It refers to the efficient production of individualized products in variable volumes, i.e., mass customization (Dombrowski and Wagner 2014). Further, higher customer satisfaction and an increased flexibility for changing customer demand are expected. Competitiveness includes, besides an increased competitiveness in general, benefits regarding cost and profit (contributing to financial benefits), market responsiveness, and a shorter time-to-market. For instance, Schuh et al. (2014b) and Davis et al. (2012) state that costs per unit decrease and higher profits can be achieved through shorter time-to-market. Sustainability, considered indispensable for a company’s long-term success (Perrot 2015), is another benefit that also contributes to resource efficiency on the operational level. While benefits addressing sustainability in general are mentioned in some publications, others address ecologic sustainability specifically. For instance, Schuh et al. (2015b) elaborate on how Industry 4.0 ultimately enhances ecological sustainability.

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<tr>
<td>business model [6]</td>
<td>i.a. innovative business models; improved or novel business processes within value creation along product life cycle; new market opportunities; new value-creation opportunities</td>
</tr>
<tr>
<td>Competitiveness [13]</td>
<td>i.a. increased competitiveness; maintain competitiveness through mass customization; production of individual products at reasonable cost; lower cost per piece; reduction of cost pressure; reduction of pressure regarding demands for individualized products; improvement of time-to-market; improved ability to respond to varying market demands</td>
</tr>
<tr>
<td>product innovation &amp; improvement [18]</td>
<td>i.a. individualization of products; innovative, complementary products and services; enhancement of product design and in-product services; additional customer-value on use; extension of products with digital services; improvement of next product generations; distribution of product information to customer; reduction of product failure risk</td>
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<tr>
<td>alignment of production to changing, individual customer demands [17]</td>
<td>i.a. product individualization; mass customization; lot size one; optimized product customization; increased customer satisfaction; rapid response to changing customer needs and individual customer requirements; alignment of manufacturing with customer demand through flexible production</td>
</tr>
<tr>
<td>Sustainability [5]</td>
<td>i.a. maximizing environmental sustainability; benefits for sustainability; improved processes sustainability; sustainable practices</td>
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**Table 4. Strategic Benefits of Industry 4.0**

In the organizational dimension, assistance of the worker is expected to benefit from Industry 4.0 by new ways of support, for example, through advanced gathering, processing, and visualization of process date (Schuh et al. 2015a) and virtual instructions at the point of action through smart devices (Weyer et al. 2015). Further, working conditions are expected to ameliorate through novel tasks, human-centric production systems, and health related issues. Rudtsch et al. (2014) mention that human-centered production processes enable production processes to follow human speed and instruction. Moreover, decoupling the place of work from the location of the worker by wireless technology will increase the mobility of humans in production. Further, coping with demographic change constitutes the third organizational benefit as Industry 4.0 technologies can contribute to less burdening work systems (Hummel et al. 2015).

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<tr>
<th>Benefit</th>
<th>Related Concept</th>
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<tbody>
<tr>
<td>coping with demographic change [1]</td>
<td>i.a. less burdening work systems to cope with intensifying demographic change</td>
</tr>
<tr>
<td>assistance to the worker [4]</td>
<td>i.a. context-aware assistance to people and machines in task execution; task simplification; new ways of gathering, processing, and visualization process data; virtual instructions and sensor-based monitoring</td>
</tr>
<tr>
<td>improved working conditions [7]</td>
<td>i.a. improved health; better working environment; assistance towards more productive, less burdening work; decoupling of workplace from physical location of worker; human-centered production processes regarding speed and instructions; adjustment to human workforce</td>
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**Table 5. Organizational Benefits of Industry 4.0**
Managerial Implications and Challenges

In the following, we discuss managerial implications and challenges gained in the course of our research that should be considered in the strategic alignment of companies in all manufacturing industries:

1. The structured processing of benefits revealed that not all benefits, although allocated to separate dimensions with varying scope, are independent from each other. Some benefits are rather mutually dependent and complementary. Thereby, it appears that the implementation of Industry 4.0 technologies to achieve benefits on the operational level is often times a precondition for the realization of benefits on managerial or strategic levels. For instance, the realization of strategic benefits like the alignment of production to changing, individual customer demands requires the realization of production flexibility or an accelerated product development process. Accordingly, the manifold interdependencies inherent in potential benefits must be considered by management, especially in terms of cause-effect relations to determine which benefits are intertwined and to identify all benefits resulting from the implementation of certain enabling technologies.

2. The benefits’ assignment to the respective framework dimensions revealed that the line between operational and managerial benefits rather vanishes through the developments of Industry 4.0, especially regarding the production system. Examples for this transformation identified in the framework are benefits concerning adaptability, utilization, optimization, predictive maintenance, or autonomous problem handling. These result from the capability of production systems to provide real-time information on an unprecedented fine-granular level and, thus, to self-control the production process in real-time, a key-characteristic of Industry 4.0. This ability influences traditional planning processes and contributes to an amalgamation of operational and managerial tasks. Thus, management faces the challenge to adapt its managerial processes, accordingly.

3. While some benefits are commonly mentioned to describe the concept of Industry 4.0 (Neugebauer et al. 2016), they are often times not set in context with concrete enabling technologies. Thus, guidance on how to realize specific benefits by means of enabling technologies is missing. This was also found by Strozzi et al. (2017), who state that research focuses primarily on conceptual work and experiments and rarely discusses actual test-beds and lessons learned from practice. Accordingly, management faces the challenge to determine concrete investment measures in enabling technologies and to develop robust transformation roadmaps in the course of their digitalization strategy.

4. Yet, some articles mention first examples for implemented benefits and their enabling technologies. For instance, Herterich et al. (2015) conduct case-studies regarding impacts of CPS on industrial services. Their benefits can be assigned primarily to operational benefits including a reduction of downtime or an increased fix time and rate. This leads to the impression that operational benefits might appear earlier, whereas strategic benefits might materialize on a longer time horizon. A survey conducted by the American Society for Quality mentioned by Banham (2015) gives a similar impression. It reveals that 82% of manufacturers could realize production efficiency gains and 49% could reduce product defects by investing in smart machines. Also, 45% could increase customer satisfaction, which constitutes a strategic benefit. Therefore, management needs to critically review the impacts of employed technologies and establish measures to assess benefits on a longer time horizon. To evaluate the success of ex-ante pursued benefits, performance indicators should be developed enabling the ex-post evaluation of benefits and their realization. For this, our benefits framework can serve as a starting point.

5. The magnitude and diversity of benefits revealed by our analysis and the accompanying costs and risks of investments clearly indicate the importance for management to systematically evaluate Industry 4.0 technologies and to apply structured approaches to manage benefits actively (Peppard et al. 2015). Accordingly, the comprehensive evaluation of Industry 4.0 technologies requires appropriate qualitative and quantitative methods of economic investment and decision theory. Our structured overview of possible benefits can serve as a starting point, for instance, for a structured benefits management approach by means of a benefits dependency network as presented by Peppard et al. (2015).

Conclusion, Limitations, and Outlook

The developments of Industry 4.0 lead to the advancing digitalization of production facilities and the development of digital enhanced business models promising great potentials in all manufacturing sectors. The accompanying changes are anticipated to transform business strategies and success models posing a...
fierce pressure on companies to deal with these developments in a proactive manner. Despite the obvious importance, there was no comprehensive picture of the contribution of Industry 4.0 technologies to the value creation of companies as a structured overview over the benefits of Industry 4.0 was missing. However, this is necessary for a comprehensive identification and subsequent quantification of benefits in regard to value-based investment decision strategies. Therefore, our work contributes to research by developing a structured benefits overview. For this, we identified 365 benefits anticipated in literature, consolidated them to 24 conclusive benefits and categorized them into an IS benefits framework. Our overview demonstrates the different dimensions in which Industry 4.0 technologies contribute to value creation. It becomes apparent that their strategic value resides in optimizing internal and cross-company value creation processes and the opportunity to develop new products and business models.

Despite the merits of this paper in terms of systematically structuring the benefits of Industry 4.0, there are some limitations, which can be noted as potential areas for further research. For instance, our analysis only includes benefits that are mentioned in scientific literature. Therefore, potential benefits that are not considered by researchers, or cannot be conceived yet, are missing. Moreover, this neglects potential findings only included in non-scientific publications. Further, in our literature analysis, we did not consider whether benefits are the focus of an article or only listed for motivational or descriptive purposes. Thus, research building up on our framework has to consider that the feasibility of the latter might not be thoroughly researched yet. Additionally, anticipated benefits in literature address different hierarchical levels (e.g., reduction of waste vs. increase of competitiveness) and are in some cases mutually dependent regarding their realization. This represents a starting point for further research on the hierarchy of benefits, on cause-effect-chains, and on causal relations among complementary benefits that could be displayed by benefit dependency networks (Ward and Daniel 2006). Additionally, we categorize the identified benefits in an adapted IS benefits framework. Future research should examine whether there are other ways of benefits categorization that would also be promising and possibly even more appropriate. So far, there is no empirical evidence in literature and, at the same time, great uncertainty in practice about which of the anticipated benefits might truly become reality. We refrained from theoretically operationalize the respective benefits as the concrete extent and value of a benefit is highly use-case specific and would have exceeded the scope of this paper. Thus, the evaluation and quantification of benefits under consideration of risk and return aspects is another important topic for further research. The same holds true for the development of concrete transformation roadmaps and digitalization strategies that support companies in deriving an appropriate portfolio and sequence of Industry 4.0 projects.

Despite these limitations and open topics for further research, we strongly believe that the developed benefits framework contributes to research on Industry 4.0 and presents a first step in enabling decision makers to identify relevant fields of actions, to develop comprehensive business strategies, and consequently, to derive value from the realization of Industry 4.0 investments.

REFERENCES

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