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Research paper

Industry 4.0 and the current status as well as future prospects on logistics

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ABSTRACT

Industry 4.0, referred to as the "Fourth Industrial Revolution", also known as "smart manufacturing", "industrial internet" or "integrated industry", is currently a much-discussed topic that supposedly has the potential to affect entire industries by transforming the way goods are designed, manufactured, delivered and payed. This paper seeks to discuss the opportunities of Industry 4.0 in the context of logistics management, since implications are expected in this field. The authors pursue the goal of shedding light on the young and mostly undiscovered topic of Industry 4.0 in the context of logistics management, thus following a conceptual research approach. At first, a logistics-oriented Industry 4.0 application model as well as the core components of Industry 4.0 are presented. Different logistics scenarios illustrate potential implications in a practice-oriented manner and are discussed with industrial experts. The studies reveal opportunities in terms of decentralisation, self-regulation and efficiency. Moreover, it becomes apparent that the concept of Industry 4.0 still lacks a clear understanding and is not fully established in practice yet. The investigations demonstrate potential Industry 4.0 implications in the context of Just-in-Time/Just-in-Sequence and cross-company Kanban systems in a precise manner. Practitioners could use the described scenarios as a reference to foster their own Industry 4.0 initiatives, with respect to logistics management.

1. Introduction

"The implementation starts with small steps here and there, there won't be a big bang that is going to introduce Industry 4.0. On the contrary, it will come step by step. But if we look back in ten years we will see that the world has changed significantly." *([1]Hartmut Rauen, Deputy Executive Director Mechanical Engineering Industry Association (VDMA), 2012).*

In recent years, complexity and requirements in the manufacturing industry have steadily increased. Factors such as growing international competition, increasing market volatility, demand for highly individualised products and shortened product life cycles present serious challenges to companies [2]. It seems that existing "approaches" of value creation are not suited to handle the increasing requirements regarding cost efficiency, flexibility, adaptability, stability and sustainability anymore. On one hand, requirements in the manufacturing industry have increased. On the other hand, the rapid technological progress in the more recent past has opened up a range of new business potentials and opportunities. Trends and new catchwords such as digitalization, the internet of things (IoT), internet of services (IoS) and cyber-physical systems (CPS) are becoming more and more relevant. Against this backdrop, Germany, which is well known for its strong manufacturing sector, launched the so-called "Industrie 4.0" initiative in 2011 as part of its high-tech strategy, introducing the idea of a (fully) integrated industry [3,4]. Since then, Industry 4.0 has gained attention importance – also beyond the German-speaking area – and has even been listed as a main topic on the 2016 World Economic Forum's agenda.

Prophetically, Kagermann et al. [5] expect that strong industrial nations such as Germany will only remain successful if they manage to actively participate in the Industry 4.0 initiative. In concrete terms, this means participating in the development, merchandising and operation of autonomous, knowledge- and sensor-based, self-regulating production systems. The opportunities and benefits that are anticipated to come along with Industry 4.0 seem to be manifold, e.g. resulting in highly flexible mass production, real-time coordination and optimisation of value chains, reduction of complexity costs or the emergence of entirely new services and business models.

As far as the field of logistics is concerned, major implications are predicted, too. In fact, logistics represents an appropriate application area for Industry 4.0 [3]. The integration of CPS and IoT

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into logistics promises to enable a real-time tracking of material flows, improved transport handling as well as an accurate risk management, to mention but a few prospects. In fact, one could argue that Industry 4.0 in its pure vision can only become reality if logistics is capable of providing production systems with the needed input factors at the right time, in the right quality and in the right place.

As promising as the idea of a self-prophesying "Fourth Industrial Revolution" may sound at first sight, it is essential to remark that there is a multitude of challenges, risks and barriers with regard to its implementation. Traditional industry boundaries will vanish due to the reorganisation of value creation processes and cause severe changes within and across organisations. Defining appropriate infrastructures and standards, ensuring data security and educating employees are among the issues that need to be addressed on the road to Industry 4.0.

Unsurprisingly, a huge number of practitioner-oriented articles and papers address the opportunities of Industry 4.0 and seek to motivate (or even urge) companies to participate in the initiative. Although the term Industry 4.0 roots back to Germany's high-tech strategy and thus has received a lot of attention recently, it still lacks a precise, generally accepted definition. This situation must be considered unsatisfying, especially from a scientific point of view.

The present paper picks up on this deficit and aims to sharpen critically the picture of Industry 4.0 with regard to logistics management, since major consequences are expected in this field. Based on a theoretical and conceptual ground work, the authors select some prominent logistics concepts so as to describe potential implications and pitfalls of Industry 4.0 in detail. After that, the findings are reflected and discussed with experts in terms of practical feasibility.

Against this backdrop, our ambitions are reflected by the following research question:

What are the implications of Industry 4.0 for future logistics management? In particular: How may Industry 4.0 affect logistics concepts, namely Kanban and Just-in-Time/Just-in-Sequence?

Current research still lacks consistent knowledge about how the "Fourth Industrial Revolution" is going to affect future industries. Against this background, we follow a conceptual research approach as described by Meredith [6], serving an exploratory purpose so as to provide a better understanding of this rather undiscovered topic. The research process can be divided into the following phases: The initial phase was devoted to narrowing down the topic and its scope. This was accomplished first through multiple unstructured discussions within the affiliated research team of the authors as well as through desk research. Following that, the authors conducted a literature review on the topic of Industry 4.0 in the second phase. The reason for examining past and current literature was twofold: On one hand, the review was conducted in order to investigate the background and origin of Industry 4.0. On the other hand – with respect to the fact that Industry 4.0 has become a buzzword recently but still lacks a generally accepted conceptual understanding – it served the purpose of identifying its key components and characteristics so as to sharpen the picture. In the third and main phase of this paper, we try to investigate potential implications and pitfalls of Industry 4.0 in the field of logistics management and thereupon construct and describe a number of scenarios with regard to specific logistics concepts. The findings are summarized in propositions. Moreover, eight experts in the field of logistics and supply chain management are interviewed in order to evaluate the propositions. The final phase comprises a (self-)critical review of the research process and findings by the authors.

With regard to the structure of this paper, four main parts can be distinguished: The first section of the paper is devoted to introducing and emphasizing the topicality of Industry 4.0. Moreover, the aim, research question, structure and methodology are covered. Following that, a comprehensive literature review on the subject of Industry 4.0 is conducted in the second part so as to lay a solid theoretical foundation for the subsequent research. In Section 3, two well known logistics concepts are analysed with respect to potential Industry 4.0 consequences. Experts from different industries are then questioned in order to evaluate the findings in terms of practical relevance. The last part of the paper comprises a critical review of the core findings and thereupon offers suggestions for future research.

2. Literature review

2.1. Industry 4.0 emergence

The industrial sector plays a crucial role in Europe, serving as a key driver of economic growth (e.g. job creation) and accounting for 75% of all exports and 80% of all innovations [7]. However, the European manufacturing landscape is twofold. While Eastern Europe and Germany show a constantly growing industrial sector, many Western European countries such as Great Britain or France have experienced shrinking market shares in the last two decades. While Europe has lost about 10% of its industrial share over the past 20 years, emerging countries managed to double their share, accounting for 40% of global manufacturing. A few years ago, Germany started thinking about initiatives in order to maintain and even foster its role as a "forerunner" in the industrial sector. Eventually, the term Industry 4.0 was publicly introduced at the Hanover Trade Fair in 2011, presented as part of Germany's high-tech strategy so as to prepare and strengthen the industrial sector with regard to future production requirements [8]. While the IoT is assumed to take on a leading role in the Industry 4.0 era, Hermann et al. [9] found that the IoS will find its way into factories, too. CPS, which are able to interact with their environment via sensors and actuators, constitute another element of Industry 4.0, since they are expected to enable factories to organise and control themselves autonomous in a decentralised fashion and in real time [4]. Due to their capabilities, these factories are often referred to as "smart factories". Given all these concepts, the difficulty of finding a unique and concise definition for Industry 4.0 becomes apparent, and it is hardly surprising that opinions among researchers and practitioners diverge. Moreover, it is still uncertain how Industry 4.0 will manifest itself in practice and how much time that will take. With respect to a more precise understanding of the topic, we now try to clarify the core components of Industry 4.0.

2.2. Industry 4.0 key components

Hermann et al. [9] identified four Industry 4.0 key components based on a review of academic and business publications, using different publication databases so as to ensure objectivity. These key components are now briefly described.

Cyber-physical systems (CPS): Industry 4.0 is characterised by an unprecedented connection via the internet or other distributed ledgers and so-called CPS, which can be considered systems that bring the physical and the virtual world together [10]. More precisely, "cyber-physical systems are 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" ([11]; p. 1). In the manufacturing context, this means that information related to the physical shop floor and the virtual computational space are highly synchronised [12]. This allows for a whole new degree of control, surveillance, transparency and efficiency in the production process. With regard to their structure, CPS have "two parallel networks to control, namely a physical network of interconnected components of the infrastructure and a cyber network comprised of intelligent controllers and the communication links among them" ([13], p. 928). CPS realise the integration of these networks through the use of multiple sensors, actuators, control processing units and communication devices.

Internet of things (IoT): The term "internet of things" became popular in the first decade of the 21st century and can be considered an initiator of Industry 4.0 [14]. "Smart, connected products offer exponentially expanding opportunities for new functionality, far greater reliability, much higher product utilization, and capabilities that cut across and transcend traditional product boundaries" [15]Porter and Heppelmann, 2014; p. 4). Also Nolin and Olson [16] note that the IoT "seems to envisage a society where all members have access to a full-fledged Internet environment populated by self-configuring, self-managing, smart technology anytime and anywhere" (p. 361). The IoT is expected to open up numerous economic opportunities and can be considered one of the most promising technologies with a huge disruptive potential. For the purpose of clarification, Fleisch [17] stresses the need to distinguish the IoT concept from the "ordinary" internet, arguing that "the nerve ends in the IoT are very small, in many cases even invisible, low-end and low energy consumption computers [. . .] whereas the nerve ends of the Internet are full-blown computers" (p. 3). Moreover, the number of network nodes in the IoT is significantly higher than in the conventional internet ("trillions versus billions"). Eventually, literature provides a wide range of definitions for the IoT. Some of them are very specific, other ones feature a more general character. For pragmatic reasons, this paper sticks to a rather comprehensive definition by referring to the IoT as a world where basically all (physical) things can turn into so-called "smart things" by featuring small computers that are connected to the internet [17].

Internet of services (Io):SIt is often said that we are living in a so-called "service society" these days [18]. With respect to that, there are strong indications that, similar to the IoT, an internet of services (IoS) is emerging, based on the idea that services are made easily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services [19]. It can be assumed that internet-based market places of services will play a key role in future industries. Whereas from a pure technological perspective, concepts such as service-oriented architecture (SOA), software as a service (SaaS) or business process outsourcing (BPO) are closely related to the IoS, Barros and Oberle [20] propose a broader definition of the term service, namely "a commercial transaction where one party grants temporary access to the resources of another party in order to perform a prescribed function and a related benefit. Resources may be human workforce and skills, technical systems, information, consumables, land and others" (p. 6).For the purpose of this paper, we will follow the latter definition.

Smart factory: Up to now, CPS, the IoT and IoS were introduced as core components of Industry 4.0. It must be noted that these "concepts" are closely linked to each other, since CPS communicate over the IoT and IoS, therefore enabling the so-called "smart factory", which is built on the idea of a decentralised production system, in which "human beings, machines and resources communicate with each other as naturally as in a social network" ([14]; p. 19). The close linkage and communication between products, machinery, transport systems and humans is expected to change the existing production logic. Therefore, smart factories can be considered another key feature of Industry 4.0. In the smart factory, products find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet highly flexible and individualised mass production. [14] note that smart factories "will make the increasing complexity of manufacturing processes manageable for the people who work there and will ensure that production can be simultaneously attractive, sustainable in an urban environment and profitable" (p. 21). Hence, the potentials that might come along with smart factories are expected to be huge. It is important to understand that not only production processes but also the roles of employees are expected to change dramatically. Spath et al. [2] expect employees to enjoy greater responsibility, to act as decision makers and to take on supervising tasks instead of driving forklifts, for instance. In the same context, some critics have recently pointed out that the automated and self-regulating nature of the smart factory might cause severe job destruction. However, hardly any reliable study supports that fear.

Beyond these key components, there is an increasing set of further Industry4.0-technologies in a broader sense, such as wearables (e.g. smart watches, glasses or gloves), augmented reality applications, autonomous vehicles (incl. drones), distributed ledger systems (e.g. the blockchain[1]) or even big data analytics.

As a first preliminary summary, we define Industry 4.0 as follows:

- Products and services are flexibly connected via the internet or other network applications like the blockchain (consistent connectivity and computerization).
- The digital connectivity enables an automated and self-optimised production of goods and services including the delivering without human interventions (self-adapting production systems based on transparency and predictive power).
- The value networks are controlled decentralised while system elements (like manufacturing facilities or transport vehicles) are making autonomous decisions (autonomous and decentralised decision making).

With respect to logistics management, Industry 4.0 is expected to achieve opportunities in terms of decentralisation, self-regulation and efficiency.

3. Industry 4.0: implications for logistics management

3.1. Approach

We now aim to answer the question whether logistics management might be affected by Industry 4.0. Thereby, we follow the conceptual research approach suggested by Meredith [6]. Our argumentation is based on a simple logistics-oriented Industry 4.0 application model as described in Fig. 1. The model encompasses two dimensions:

(1) *Physical supply chain dimension:* Autonomous and self-controlled logistics sub systems like transport (e.g. via autonomous trucks), turnover handlings (e.g. via trailer unloading or piece picking robots) or order processing (e.g. via smart contracts on the blockchain technology) are interacting among each other.
(2) *Digital data value chain dimension:* Machine and sensor data are collected at level of the "physical thing" along the entire

[1] The blockchain is a distributed, public ledger which is collectively kept up to date according to strict rules and general agreement. The technology behind solves a well-known computer science problem called "The General Byzantine Problem" described by [34]. The blockchain enables to reach a consensus in a system with potentially malicious actors and without a central authority ([35]; p. 82).

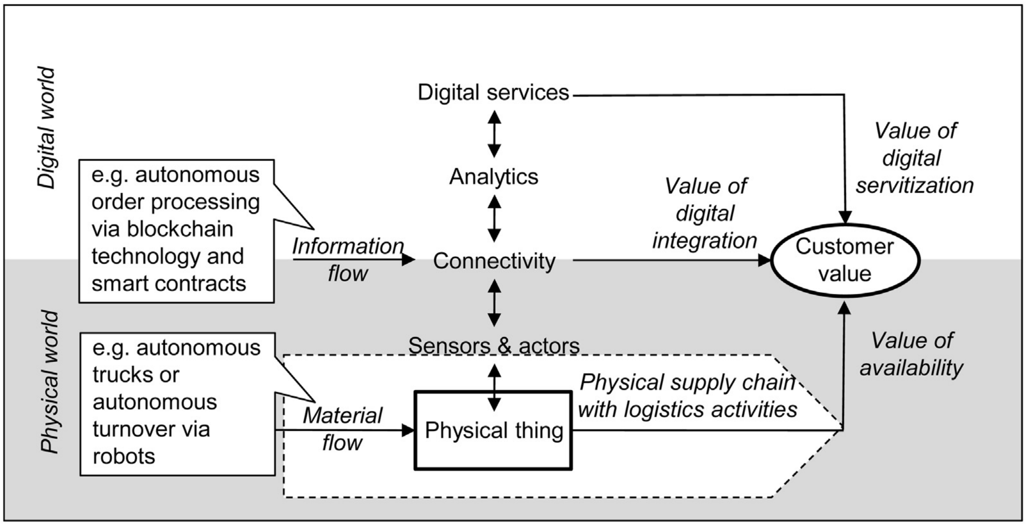

Fig. 1. A logistics-oriented Industry 4.0 application model.
(Source: According to [39; p. 7])

physical end-to-end supply chain. Via a connectivity layer the gathered data is provided for any kind of analytics (e.g. in the cloud), possibly resulting in potential value-added business services.

Out of this two-dimensioned application model, three customer value components are expected. First, the "value of availability", meaning making products and services available to the customer via autonomous delivering. Value creation through availability of goods or services is the main added value of logistics activities and services. Second, "value of digital integration" arises through a permeable transparency and traceability along the supply chain. Furthermore, order processing systems are interconnected, facilitating seamless business executions (e.g. object self-service, remote usages or condition monitoring). Third, consumption normally exceeds the classical point-of-sale (POS), but this does not mean that the supply chain ends at this point. There exist several IT-based service options going beyond the simple distribution of products or physical services (="value of digital servitization"). Aside digitally charged things where physical products are "charged" with additional digital services, the data itself creates value outside the original use case ("sensor as a service").

The units of analysis are common and well established logistics concepts. It is assumed that these concepts will pass through a digital transformation, too. Thus, the following needs to be kept in mind: First of all, it is not possible to consider all ideas, concepts and elements of Industry 4.0. Consequently, the scenarios only comprise a selection of those. Moreover, the described effects do no feature an exclusive character, meaning that if it is suggested that Industry 4.0 may affect concept x (e.g. cross-company Kanban) in a particular way, it might also affect concept y (e.g. JIT/JIT) in a similar way. Given these constraints, the authors do not seek to provide generally valid statements about how Industry 4.0 will affect logistics management, but rather aims to illustrate and discuss "some" potential use cases. Based on a comprehensive literature review, the main process steps and activities (phases) of the selected logistics concepts were elaborated. For each of these phases, potential implications of Industry 4.0 were identified. Here, in each case the central characteristics and components of Industry 4.0 are mentioned. Furthermore, real world examples and approaches were identified for illustrative reasons if possible. The central findings were further summarized in propositions. Finally, the results were subsequently reflected again with the experts. If it has been appropriate and necessary, adjustments were made in formulating. A critical discussion completes the explorative research.

3.2. Selection of logistics concepts for the industry4.0 analysis

Our selection is based on three aspects. First, the concepts should comprise a cross-organisational component and therefore be closely related to logistics and supply chain management. Recently, articles and papers often focus on specific "intra-logistics" areas – e.g. production logistics (e.g. [21,22] or [23] – and hereby ignore cross-organisational aspects. Second, the concepts have to be considered relevant to the practical world in terms of acceptance and distribution. The authors used the publication database EBSCOhost as well as the scholarly literature search engine Google Scholar so as to underline the importance of these concepts. The databases were searched with respect to publications with a clear reference to the concepts in either their title or abstract. Given the search string results displayed in Table 2, four concepts – namely cross-company-oriented Kanban, JIT/JIS,

Table 1
Search String Results.

Logistic concepts (Search Term(s))	Number of Publications in which Search Term(s) occurred in Title or Abstract	
	EBSCOhost (academic journals only)	Google Scholar (Title only)
Just-in-Time (JIT)/Just-in-Sequence (JIS)	1636	7109
Kanban (cross-company-oriented approach)	1029	2200
Vendor Managed Inventory (VMI)	539	799
Cross-docking	165	565

VMI and Cross-docking – are localized. Third, the concepts should be susceptive for fully automated implementations. In such a case the machines will directly communicate and transfer materials with each other without involving any visible intervention or human work. The concepts cross-company-oriented Kanban and JIT/JIS are two important operational-level techniques which may be affected by new technologies, such as IoT or autonomous transport. They seem to be more appropriate to be discussed in the context of Industry 4.0 as compared to those tactical-level approaches such as VMI and Cross-docking (Table 1).

3.3. Just-in-Time (JIT) and Just-in-Sequence (JIS)

3.3.1. Backdrop

Just-in-Time (JIT) is a prominent and widely accepted concept in production and logistics, especially in the automotive industry. Similar to the previously discussed Kanban concept, JIT follows a lean approach and is strictly pull oriented, meaning that material is only produced and supplied in case of an actual demand. JIT primarily focuses on the supplier-buyer relationship and can therefore be considered a cross-company approach. Its main objective is to realise a zero- or low-stock supply system. Moreover, JIT seeks for a demand-tailored realisation of goods exchange processes within and across companies as well as short delivery respectively cycle times. Finally, JIT aims to increase overall supply chain flexibility and agility [29]. However, the implementation of JIT systems is far from trivial. First of all, production planning needs to be precisely aligned to actual demand. Furthermore, a high level of integration with regard to material and information flows needs to be established, since there is only little or no inventory kept as a buffer, e.g. in case material is directly shipped from the supplier's production facility to the buyer's production facility without temporary storage. Against this backdrop, a close coordination between suppliers and buyers is a prerequisite for success [30]. Finally, it has to be mentioned that a JIT strategy is primarily suited in case of high-value products that are consumed on a constant, well-predictable basis.

Whereas – in short – JIT calls for the right material to be supplied at the right time and in the right place, the so-called Just-in-Sequence (JIS) concept goes one step further by ensuring that the material also arrives in the right sequence with respect to its further processing. Hence, incoming material does not have to be sorted by the buyer anymore. JIS can therefore be considered an enhancement of JIT, which means that, apart from additional benefits (no sorting etc.), requirements are even higher, especially with regard to transport planning.

3.3.2. Potential implications of industry 4.0

JIT/JIS systems generally pass the following process steps and activities: (i) production planning, (ii) production order, (iii) disposition and production, as well as (iv) delivery. Table 2 illustrates how JIT/JIS systems may be impacted by Industry 4.0. Since JIT/JIS particularly rely on planning accuracy, information transparency and well-coordinated transport processes, a special focus is put on these areas.

Fig. 2 again illustrates the typical process steps and activities of JIT/JIS systems, highlighting the main implications of Industry4.0.

As production planning is crucial in JIT/JIS systems, the increasing use of Auto-ID technologies has the potential to facilitate production planning or even make it futile (step 1). With respect to the coordination between supply chain actors, cloud or distributed ledger technology might enable the creation of a virtual ERP system for the whole supply chain, so that all actors can share and act upon the same information. Bullwhip effects may therefore be avoided or reduced (steps 2 & 3). Moreover, transport processes, which are also highly important in JIT/JIS so as to ensure delivery at the right time, might be coordinated in an end-to-end fashion across the whole supply chain (step 4). In conclusion, Industry 4.0 provides the opportunity to improve JIT/JIS systems, since it may enable actors to exchange and act upon real-time information in a coordinated end-to-end fashion.

3.3.3. Derivation of JIT/JIS-related propositions

Now, the key implications of Industry 4.0 with regard to JIT/JIS are discussed with two supply chain management experts and propositions (PP) were derived.

Interviewed Experts	Industry 4.0 Related Knowledge & Experience
Expert 3: Supply Chain Specialist at a Medical Device Company	Moderate knowledge, based on literature
Expert 4: Project Leader Supply Chain and Logistics at a Commercial Vehicle Technology Company	Moderate knowledge, mainly based on literature and discussions with colleagues

$PP1_{JIT/JIS}$: Industry 4.0 will enable an increasingly automated, decentralised and more accurate demand planning and forecasting in JIT/JIS systems, since material consumption and material flows – e.g. inbound and outbound flows – can be tracked precisely and close to real time through the use of CPS and Auto-ID systems.

The experts partially agree with the proposition. Expert 3 mentions that one has to differentiate between long-term and short-term demand planning. As far as the latter is concerned, he in fact believes that a real-time tracking of material flows and consumption can improve demand planning. However, with respect to long-term demand planning – especially in case of products with long replenishment times – Expert 3 does not expect real-time information to have a significant potential, arguing that it does not matter whether one gets a particular information on day x or on day x + 1, since replenishment will take a long time anyway. Expert 4 agrees with this argument and adds that in the automotive industry (where JIT/JIS is primarily applied) information transparency is already on a high level, meaning that there is no substantial need for real-time data.

$PP2_{JIT/JIS}$: Industry 4.0 will enable a high degree of process integration along the supply chain. Virtual, e.g. cloud-based ERP or distributed ledger systems for the whole supply chain will increase end-to-end transparency and automated execution of JIT/JIS systems. Against this backdrop, processes will not be planned and executed individually by single actors anymore, but in an integrated fashion across the supply chain.

Expert 3 agrees with the statement, arguing that a uniform system, which integrates all supply chain actors, offers potential with regard to overall coordination. He further notes that cloud computing might indeed be a promising approach, since cloud

Table 2
Characteristics of Industry 4.0 Scenario for Just-in-Time/Just-in-Sequence.

~~Just-in-Time~~/Just-in-Sequence: Process Steps and Activities	Industry 4.0 Scenario	Industry 4.0 Characteristics & Components	Selected Real-World Examples and Approaches
1. Production planning Precise planning of production based	Through the increasing traceability of material and products that are equipped with Auto-ID technology, production	Real-time tracking of material flows Supply chain integration	Smart Sales and Distribution, Smart Shopfloor & Planning by Fistec enables companies to track material flows (in-

Table 2 (*Continued*)

Just-in-Time/Just-in-Sequence: Process Steps and Activities	Industry 4.0 Scenario	Industry 4.0 Characteristics & Components	Selected Real-World Examples and Approaches
on (future) demand patterns respectively forecasts.	planning may be far more accurate in Industry 4.0, since material flows – e.g. inbound and outbound flows at a selling point – can be tracked in real time and therefore allow for a precise deduction of demand patterns. Moreover, deterministic production planning might shrink to a minimum or even become futile, if material flows can be tracked precisely. If a product is consumed or sold at a particular point in the supply chain, all relevant players (suppliers) get an immediate notification and adjust their production according to the current demand. In this case, so-called bullwhip-effects might be avoided or mitigated, since all players would be able to act on the same (real-time) information.		and outbound) closely via mobile devices and allows for a more effective and comfortable use of ERP systems [25; p. 70].
2. Production order Based on the production planning, the buyer sends an order to the supplier (s), requesting the exact amount of material that is required.	Industry 4.0 promises highly integrated material and information flows across the whole supply chain. This may result in more efficient JIT/JIS-systems, since e.g. real-time consumption of products may automatically trigger supply orders or inform suppliers about the consumption. Hence, production orders are aligned with actual consumption, meaning that as soon as a particular product is consumed or required, a re-supply order is released. Full transparency across the supply chain could be realised through e.g. a cloud-based ERP system or a distributed ledger system (blockchain technology) that integrates the whole supply chain respectively its actors. If demand arises at a particular point in the supply chain, all relevant suppliers might get an immediate order to produce the needed components.	• Digital reflection of supply chain activities and processes • Integrated material and information flows • Supply chain integration through cloud or blockchain technology	Ultriva's Collaborative Supply Portal enables full visibility into demand and supply and improves collaboration between supply chain partners through the use of a single platform for demand signals, order management and goods shipment [27].
3. Disposition & production Consumption (by the buyer) is transmitted in real time and triggers the supplier's production.	Suppliers get real time information and updates consumption at a buyer's site and are therefore able to improve their production planning, since consumption data is transmitted immediately and continuously (not discretely). As a result, suppliers gain additional flexibility (time advantage) and JIT/JIS cycle times might be reduced.	• Decentralised decision-making/self-regulation • CPS • Connected plants and production facilities	N.A.
4. Delivery The supplier commits to deliver the right material at the right time, in the right place and – in case of JIS – in the right sequence with regard to the further processing of the material.	Intelligent routing systems promise huge potential with regard to a just-in-time delivery. Telematics units for instance may be used to track the freight's location or state-related data such as air pressure, temperature etc. during transportation and advise the carrier (e.g. the truck driver) with information regarding traffic or weather, enabling her/him to adjust the route. In case of fully transparent and integrated supply chains, delivery respectively transport processes might be optimised across the entire supply chain. Simulation tools might help to calculate adequate transportation given the specific order requirements (e.g. timing). Transport processes may therefore not be planned individually anymore, but in an integrated end-to-end fashion. In the long run, the collection and delivery could fulfilled by autonomous and self-driving trucks.	Condition monitoring Simulation of processes Supply chain integration Integrated mobile information systems	MAN-telematics and Volkswagen's Car-to-X inform drivers about traffic conditions and allow traffic participants to communicate with each other through the use of position-based routing technologies and algorythms [26,28]

Sources: Banyai [24], Kutschenreiter [25], MAN [26], Ultriva [27], Volkswagen [28]

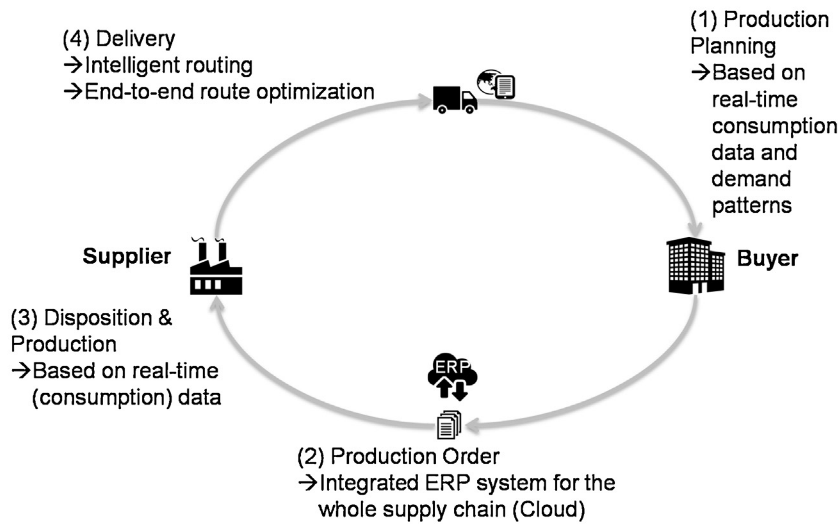

Fig. 2. Modified Just-in-Time/Just-in-Sequence cycle according the Industry 4.0 Scenario.

solutions are simple to use respectively provide an easy interface to its users. In contrast, Expert 4 believes that the idea of an integrative end-to-end perspective on supply chains does not make much sense. He argues that today's supply chains are far too complex and involve too many actors so as to manage all of them in an integrated manner on one single system. Against this backdrop, he suggests to put the focus on crucial parts or fragments of the supply chain and not on the supply chain as a whole.

3.4. Cross-company Kanban

3.4.1. Backdrop

The Kanban concept originated in Japan and, generally speaking, can be considered a scheduling system in manufacturing. Its core characteristic is a rigid pull-orientation of the production processes, which is why terms such as pull concept or pull system are often used synonymously. Henderson [31] describes Kanban as follows: "Kanban is basically the system of supplying parts and materials just at the very moment they are needed in the factory production process so that those parts and materials are instantly put to use" (p. 6). To do so, the station which has run out of material uses so-called Kanbans (Japanese word for billboard/signboard) so as to signal the precise quantity of material that needs to be supplied. The essential idea behind this concept is that the number of Kanbans respectively bins or containers determines the maximum inventory level within a "loop" between a supplying and a receiving station. The supplying station therefore only starts producing when the receiving station indicates an actual demand signal. Kanban, which is based on the idea of self-regulating loop systems, allows for a systematic reduction of inventory level and costs. In addition, a strictly demand-oriented production of rather small lot sizes alleviates so-called bullwhip effects, one of the major challenges in supply chain and logistics management. Yet, Kanban systems are suitable only if fluctuations in demand are rather small, both within the actual production system and with regard to the (end) customer. Furthermore, workforce capacity must be coordinated with respect to actual production needs. Therefore, flexible working time models might be required. Finally, especially cross-company Kanban systems only run successfully if high standards with regard to information flows and product quality can be ensured. Inaccuracies and mistakes pose a high risk and should therefore be avoided or at least be reduced to a minimum ("zero-defect policy"), since there is no or only little inventory kept in Kanban systems.

3.4.2. Potential implications of industry 4.0

Kanban systems across company boarders include the following process steps and activities: (i) demand assessment, (ii) Kanban signal, (iii) disposition and production, (iv) collection and delivery, as well as (v) goods receipt. Table 3 illustrates potential opportunities and consequences of Industry 4.0 for Kanban along the process steps.

Fig. 3 depicts the previously discussed implications and illustrates what a Kanban cycle might look like in the context of Industry 4.0. Following that, the main results are summarized concisely.

In traditional Kanban systems, demand respectively replenishment quantity is usually assessed through the "state" of bins, meaning that empty bins trigger a replenishment process. Due to the use of technologies such as RFID and sensor systems, demand assessment might follow a real-time approach in the future with only little or no need for human participation (step 1). In addition, material requirements may be digitally forwarded, whereas demand is signalled through (physical) Kanban cards or bins in conventional systems (step 2). Due to this precise and real-time oriented information flow enabled by the use of CPS (e.g. "intelligent bins"), suppliers may gain additional flexibility with regard to their replenishment activities (step 3). Furthermore, milkruns might follow a strictly demand-driven logic and therefore become highly dynamic, resulting in more efficient collection and delivery processes (step 4). Besides that, Auto-ID technology facilitates goods receipt processes (step 5).

3.4.3. Derivation of Kanban-related propositions

Based on the findings, we derived a number of propositions (PP), comprising the key implications of Industry 4.0 on the concept of Kanban. In order to discuss and evaluate the relevance and feasibility of these propositions, again expert interviews were conducted.

Interviewed Experts	Industry 4.0 Related Knowledge & Experience
Expert 1: Supply Chain Strategy Expert at an Engineering and Electronics Company	Profound knowledge, mainly based on literature, symposia and expert discussions
Expert 2: Innovation Manager at a Logistics Solution Provider	Mainly theoretical and conceptual knowledge

Table 3
Characteristics of Industry 4.0 Scenario for cross-company Kanban.

Kanban: Process Steps & Activities	Industry 4.0 Scenario	Industry 4.0 Characteristics & Components	Real-World Examples/ Approaches
1. Demand assessment Demand is assessed at a particular workstation, based on the available respectively remaining input components and workpieces, which are usually stored in Kanban containers or bins.	In an Industry 4.0 scenario, the use of Auto-ID technology – e.g. RFID tags and scanning devices – may enable an accelerated, more precise demand assessment process, since less manual interaction is required (e.g. for counting the remaining material). Human interaction may even become futile in this process if inventory levels are measured automatically by autonomous systems, e.g. RFID-reading shelves. Kanban bins might even be equipped with sensor systems that are capable of tracking fill levels and other characteristics – such as temperature or air pressure in case of sensitive material — in real time. Based on this information, bins might perform actions autonomously, e.g. release a replenishment order or initiate a depletion of bins (executed by actuators). In this scenario, bins can be considered complex CPS.	CPS Human-Machine interaction Real-time data capturing and exchange Traceability and transparency (Auto-ID)	Würth Industry Service's iBin" delivers accurate fill level and order information through the use of an integrated camera and releases supply orders automatically through RFID-technology. The 'Bayerischer Forschungsverbund' has developed a thermal container FORFood that senses and transmits information on air temperature, moisture, vibrations etc. ([3]; p. 306–307).
2. Kanban signal Demand signals are transmitted (physically) via "encoded" bins or Kanban cards, which contain specific information regarding the required material (e.g. needed quantity).	In the era of Industry 4.0, demand will be signalled digitally. Electronic Kanban systems (e-Kanbans) have been in use for several years, meaning that sensors recognise the fill level of bins. This information may be directly fed into the material planning system, which then sends a supply order respectively signal to the supplier in case the bins are empty. Kanban signals might even be transmitted in real time, meaning that the cyber-physical bins (as described above) transmit their fill levels directly to the supplier. Therefore, the supplier gets updated on material consumption in real time. In this scenario, Kanban signals are not released on a cyclical or event-driven basis anymore (e.g. when an employee realises that bins are empty).	Vertical integration (from field level to enterprise level) CPS Real-time data exchange	N.A.
3. Disposition & production The supplier receives demand signals via Kanban cards or bins (predefined lot-size!) and thereupon triggers production.	Since consumption data is transmitted closer to real time and in a continuous fashion (not event driven or cyclically), suppliers get a time advantage with regard to their production (planning). This may increase suppliers' flexibility and ability to react, e.g. in case of sudden fluctuations in demand (which often present a challenge to conventional Kanban systems). If production facilities of buyers and suppliers are able to communicate directly with each other, cyber-physical bins might initiate production at the buyer's site without any human interaction. Consumption (by the buyer) and production (by the supplier) might therefore be closely aligned and allow for a reduction of cycle times.	Decentralised decision-making/self-regulation CPS Connected plants/ production facilities	L-Mobile's RFID Kanban enables full visibility of all processes within a Kanban system through the use of RFID technology (orders, bins, material, workpieces, machines) and initiates supply automatically [33].
4. Collection & delivery Collection and delivery often follows a so-called milk run approach, meaning that the material is collected and delivered in round trips, which are commonly initiated on an interval basis (e.g. once a day) with a fixed route.	Industry 4.0 may enable a more efficient delivery of material. Due to the increasing digitization of material flows, delivery processes may be simulated with respect to adjacent processes, e.g. taking remaining production time into consideration. This is especially helpful in case of a wide range of products with different production cycles. The result would be a highly dynamic milkrun that is not time-driven (and therefore often not used to full capacity) but demand-driven. With respect to internal material flows, so-called modular material flow systems might come into play, enabling a highly flexible and autonomous transport of material. Telematics units may furthermore facilitate cross-organisational delivery respectively transport processes by e.g. assisting truck drivers with information regarding traffic etc., allowing them to optimise their route. In the long run, the collection and delivery could be fulfilled by autonomous and self-driving trucks.	(Virtual) Simulation of processes Digital reflection of factory Autonomous processes Integrated mobile information systems	The Bremer Institut für Produktion und Logistik [32] has developed a dynamic milkrun that follows a strictly demand approach and helps reduce wastage. Moreover, its celluveyor conveyor system transports material through the factory autonomously.

Table 3 (*Continued*)

Kanban: Process Steps & Activities	Industry 4.0 Scenario	Industry 4.0 Characteristics & Components	Real-World Examples/ Approaches
5. Goods receipt The buyer receives and controls the material.	Auto-ID technologies may facilitate and accelerate goods receipt processes. Employees may use a scanning device so as to identify and control incoming material respectively bins, which are equipped with Auto-ID tags. Whereas the use of scanning devices still requires human interaction, one might also install gate control systems that automatically identify incoming material and control it with regard to the respective order. In case of any defects (e.g. if delivered quantity does not match required quantity), an employee might get immediately notified via her/his cell phone or tablet that is connected to the ERP system.	Human-Machine interaction Autonomous processes Vertical integration	Fistec's Smart Warehouse/Mobile/Sales and Distribution facilitates the control material flows (e.g. inbound and outbound flows at a plant) via mobile devices ([25]; p. 70).

Sources: BIBA [32], Kutschenreiter [25], L-Mobile [33], Bauernhansl et al. [3].

PP1$_{Kanban}$: Collection and transmission of information within cross-company Kanban systems will be of an increasingly decentralised, automated and autonomous nature in an Industry 4.0 environment, with little or no human interaction through the integration of CPS and the use of Auto-ID technologies such as RFID. Especially labour-intensive activities (e.g. stocktaking) will be supported by these technologies (e.g. robotics) and will run fully autonomously in the foreseeable future.

Both experts agree with the proposition. Expert 1 observes an increasing digitalization and automation in today's value chains and in logistics. With regard to Kanban, he notes that systems such as the intelligent bin (iBin) represent typical Industry 4.0 applications, running autonomously and following a decentralised control logic. Expert 2 adds that the organisation he works for strongly engages in the development of such systems and technologies. However, both experts are unsure whether the vision of fully autonomous processes is feasible. Expert 2 notes that there exist a variety of serious challenges that need to be overcome first. Hence, he predicts that robots, CPS etc. will rather coexist with than replace logistics personnel on the shop floor.

PP2$_{Kanban}$: Since CPS and the IoT enable a real-time or close to real-time exchange of information between buyers and suppliers, flexibility and ability to react – e.g. in case of sudden fluctuations in demand – will increase in Kanban systems.

Expert 1 agrees with the proposition, arguing that market volatility will continue to increase in the future and that demand patterns will become more and more difficult to predict, which means that companies need to improve their flexibility in order to fulfil demand. According to him, the Industry 4.0 initiative particularly aims to provide solutions to enable companies to meet these requirements. Expert 2 is in support of this argumentation, noting that the ubiquitous availability of data gained and provided by CPS will increase flexibility within Kanban cycles. Yet, Expert 2 also mentions that data security might be a critical issue, arguing that many companies may have concerns with regard to potentially confidential data that could be revealed to other companies.

PP3$_{Kanban}$: Due to the high degree of integration and information sharing between suppliers and buyers, Kanban systems will follow a strictly demand-oriented approach in the future, resulting in dynamic, more efficient milkruns and shortened cycle times.

Both experts are in complete agreement with P$_3$. However, Expert 2 notes that – from a practitioner's point of view – it remains unclear whether the potential benefits from Industry 4.0 will compensate for the (substantial) investments that are required so as to make companies "ready" for Industry. Nevertheless, both experts predict that Industry 4.0 will increase the efficiency of Kanban cycles.

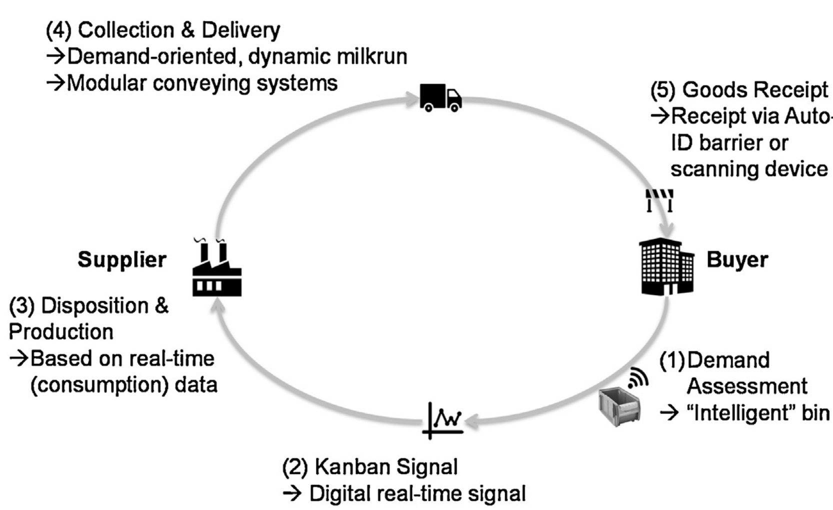

Fig. 3. Modified cross-company Kanban cycle according the Industry 4.0 scenario.

3.5. Additional findings

In addition to the concept-related propositions discussed in the preceding sections, all experts were also asked to state their opinion with regard to some concept-independent, generic propositions.

$PP1_{Generic}$: Industry 4.0 will cause a decoupling of the strategic and the operative level of logistics management. While active human decision making will still be required on the strategic level (e.g. supplier selection, site selection), the operative level (e.g. picking, loading) will be characterised by autonomously acting entities (i.e. CPS), following a decentralised decision-making approach.

Most of the experts agree with the statement that the degree of automation and autonomy on the operative level of logistics management will increase over the next years, meaning that activities such as picking, loading and stocktaking will mostly be executed by intelligent CPS. Human interaction on this level will mainly be limited to control respectively monitoring activities. In this sense, the majority of the interviewed experts expect Industry 4.0 to primarily manifest itself on the operative level. Yet, some of the experts assume that changes on the operative level will likely cause changes on the strategic level of logistics management, too. If e.g. intelligent CPS replace human workforce in the manufacturing process, certain products may not be produced in low-wage countries anymore, which means that entire supply chains may shift geographically, therefore affecting the strategic level of supply chain and logistics management (e.g. choice of location). However, the questioned experts see the majority of implications on the operative level, as noted above.

$PP2_{Generic}$: In the future, logistics processes and activities will be increasingly coordinated in an end-to-end supply chain fashion, meaning that actors will be loosely coupled into cross-network platforms (e.g. cloud-based ERP or distributed ledger systems and "logistics mall"). The efficiency and the flexibility of networks will therefore increase.

The experts indeed expect an increasing cross-organisational coordination of logistics processes and activities in the future, enabled by the digitization of processes and technologies that facilitate this form of collaboration. Expert 4 underlines this argument, noting that leading companies such as SAP are strongly engaged in the development of cross-organisational platforms in term of IoS. However, multiple experts express their concern whether a "real" end-to-end integration of supply chains is feasible, noting that there exists a variety of barriers. An Expert notes that in the automotive industry, for instance, integration of suppliers, logistics service providers (LSPs) and buyers is already on a very high level. He therefore doubts that actors are willing to invest (substantially) into new solutions or platforms or technologies (such as the blockchain) that might render marginal benefits only.

As far as the allocation of logistics services via a market place (e.g. cloud-based "logistics mall") is concerned, the majority of the experts are uncertain in terms of feasibility. Two experts argue that logistics services are often very specific, requiring a close and trustful relationship between the involved actors. Hence, these services may not be exchanged easily and therefore do not really fit the idea of a "logistics mall". Yet, the experts admit the potential of a market place model when it comes to standardised logistics services, e.g. transportation from point A to point B without any specific requirements (e.g. air pressure, temperature etc.).

4. Discussion

The first cluster of the paper was dedicated to the fundamentals of Industry 4.0. A brief literature review showed that there is no commonly agreed-upon definition and understanding of the approach yet. This finding was also confirmed by the interviews that were conducted later on. Whereas some of the questioned experts are convinced that the Fourth Industrial Revolution will change existing industries significantly, others argue that Industry 4.0 is just a collective term for technologies and concepts that have been known and applied for quite some time. According to its promotors, the Industry 4.0 initiative aims to prepare the (German) industry with respect to the future of manufacturing, which will be characterised by e.g. an individualisation of products, an increasing integration of customers and (business) partners into the value creation process and a mergence of the virtual and physical world through CPS, IoT an IoS. Yet, this description is quite vague and fails to outline the constituent characteristics and features of Industry 4.0. Is it the use of CPS in an industrial context or the combination of CPS, IoT and IoS? Or is it the digitization of value creation processes through technologies such as RFID, cloud computing and 3D printing? Or is it the decentralised and autonomous production logic?

In consideration of this theoretical and conceptual deficit, there might be a risk that Industry 4.0 becomes a so-called management fashion, which is a term referring to management concepts that relatively quickly gain large shares in the public management discourse [36]. However, management fashions usually fail to gain practical relevance in the long run, meaning that they fade under the weight of unfulfilled promises after a period of time [37]. Management fashions often evolve around highly topical issues and result in a substantial number of publications, workshops and conferences. Furthermore, management fashions are frequently used by consulting companies as an instrument to boost demand. In fact, it could be argued that Industry 4.0 fits some of the criteria of a typical management fashion. Within a relatively short period of time, the term has undoubtedly become a catchword and – in the authors' opinion – has partially fuelled excessive expectations. The fast growing number of articles, workshops etc. further underlines the popularity of Industry 4.0. Yet, a large part of those publications do not meet scientific requirements, which is another characteristic of management fashions, as Abrahamson [38] notes. This paper, just like many others, has sought to come up with arguments so as to demonstrate the opportunities and potentials of Industry 4.0. Hence, we are convinced that Industry 4.0 constitutes a sustainable concept and not just another management fashion. However, we plead for an objective, objectified and "less hyped" handling with the topic. This primarily includes the critical reflection of the potentials and promises.

The paper at hand is highly explorative in nature. We chose this approach because of the fact that the Industry 4.0 concept is still in its infancy. The interpretation and evaluation of the interviews turned out to be vague due to the fact that the interviewees' states of knowledge and experience varied greatly. Matters were complicated further by the fact that some of the experts were very enthusiastic about Industry 4.0, whereas others revealed a sceptical or even negative attitude. However, most of the questioned experts stated that Industry 4.0 has potential in the field of logistics management. This perception was supported by the fact that the majority of experts agreed with the opportunities that were described in the scenarios and propositions. Yet, some of the experts expressed doubts with regard to the practical feasibility of the scenarios. Apart from the implementation barriers that are usually mentioned in the literature, such as data security or standardisation of infrastructure, the experts perceive the increasing complexity of production and cross-organisational logistics networks as a critical barrier. This is quite interesting, since the Industry 4.0 initiative – by definition – aims to prepare and enable industries to deal with this increasing complexity. Another noteworthy takeaway from the interviews is that some of the experts question the revolutionary character of Industry 4.0, arguing that many ideas and concepts behind Industry 4.0 have been around for quite some time. Those experts are inclined to think that Industry 4.0 is just an "expression" in order to attract attention.

5. Conclusion

5.1. Key findings

Within this paper we showed that there is no commonly agreed-upon definition and understanding of Industry 4.0. In the authors' opinion, the Fourth Industrial Revolution can be best described as a shift in the manufacturing logic towards an increasingly decentralised, self-regulating approach of value creation, enabled by concepts and technologies such as CPS, IoT, IoS, cloud computing or additive manufacturing and smart factories, so as to help companies meet future production requirements. The comprehensive nature of this definition requires companies to individually define what Industry 4.0 means to them. As a consequence, there is not one single truth and reality behind this approach. Thus, this paper supports a somewhat dynamic perception, proposing an application model that comprises different dimensions and components of Industry 4.0.

The investigations in the main part revealed different Industry 4.0 opportunities in terms of decentralisation, self-regulation and efficiency. With respect to Kanban, an improved demand assessment, dynamic and more efficient milkruns as well as shortened cycle times can be expected. As far as JIT/JIS systems are concerned, reduced bullwhip effects, highly transparent and integrated supply chains as well as improvements in production planning are among the potential benefits. The interviewed experts see the majority of implications on the operative level of logistics management. Yet, besides that, the scenarios also showed the significance of Industry 4.0 with respect to cross-organisational logistics, particularly in terms of real time information flows, end-to-end supply chain transparency and improvements in flexibility, thus helping companies to optimise value-creation. Eventually, Industry 4.0 potentials should be evaluated situationally due to the complex nature of logistics management.

5.2. Limitations

The goal of this paper was to identify and discuss the implications of Industry 4.0 in the field of logistics management. Considering this, it has to be noted that the investigations did not primarily address logistics management in a general, overarching manner. Instead, the focus was limited to two logistics concepts, since it was the authors' ambition to describe the effects in a precise and detailed fashion. Against this backdrop, the present study did not seek (and is not able) to make universally valid statements about how the Fourth Industrial Revolution will affect and impact logistics management. With respect to this, the investigations and described scenarios feature a hypothetical character and should therefore be understood in their respective context. In addition to that, the focus of this paper was clearly on the potentials and opportunities of Industry 4.0, meaning that the risks, costs and implementation barriers that might accompany the digital transformation were mostly ignored. Hence, the validity of the different scenarios is limited, since only the beneficial aspects of Industry 4.0 were discussed.

In order to review and evaluate the findings, eight expert interviews were conducted. Yet, with regard to the interpretation of the results, there is a number of factors that need to be considered. On the one hand, the questioned persons all had a profound knowledge in the field of logistics and supply chain management. However, none of them considered himself/herself a specialist in the area of Industry 4.0. Thus, the level of knowledge and experience varied significantly among the interviewed experts. As a consequence, some of the dialogues were highly substantial and yielded interesting insights, whereas others merely scratched the surface of the topic. Therefore, it was difficult to directly compare the answers and opinions. Last but not least, the number of interviews was limited. In order to gain more representative and objective results, a larger base of interviews would have been required.

5.3. Recommendations for future research

Existing academic literature lacks a clear and common definition of the Industry 4.0 concept. Therefore, the image of Industry 4.0 is still quite fuzzy, both among researchers and especially among practitioners. This impression was confirmed by the interviews that were conducted in the context of this paper. Against this backdrop, future research should aim to establish a more precise understanding of what the (constituent) characteristics of Industry 4.0 are, especially for different business sectors or areas of application.

In addition to that, we suggest that companies should be accompanied and supported on their road to Industry 4.0 in a practical manner. This could be achieved through concepts and frameworks, which features different building blocks and dimensions of Industry 4.0 and therefore may serve as an orientation guideline. An applied SWOT framework, for instance, could support companies by analysing the opportunities of Industry 4.0 in the context of a company's strengths, weaknesses and environment. Moreover, an "Industry 4.0 Readiness Framework" could help identify potential implementation barriers by listing critical success factors such as availability of technology, degree of digitization, workforce capabilities and education.

Furthermore we see a strong need to concretise and substantiate the Industry 4.0 concept with regard to financials, i.e. revenue potentials and costs. In the context of the scenarios described in this paper, this could e.g. be achieved through a rough quantification of the benefits and cost advantages (e.g. reduction of inventory costs, complexity costs, wage costs) as well as the required investments (e.g. for infrastructure or employee training). We are aware of the difficulty of such a quantification. However, companies might not be willing to invest into Industry 4.0 unless they have a rough imagination of the financials.

Last but not least, the implications described in this paper need to be put into a wider context. The illustrated scenarios exclusively addressed potential consequences in the context of the respective logistics concepts. Yet, little was said about the implications beyond that. Therefore, future research should also investigate the effects of Industry 4.0 on e.g. the organisational, operational and legal structures of companies.

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