Industry 4.0 implications for supply chain collaboration – Integration of product, production, and logistics levels

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Short Paper

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Abstract

This paper summarizes the implications of Industry 4.0 for supply chain collaboration, especially the integration of product, production, and logistics levels. This horizontal and vertical integration across the entire supply chain and across the entire product lifecycle traces back to the original concept of Industry 4.0. The paper first describes data exchange of logistics data across the entire supply chain tiers, which is the predominantly described form in research and practice. Subsequently, data exchange encompassing production and logistics levels offers even more potential but is also more challenging from a cross-organizational perspective. Finally, data exchange across production, product, and logistics levels offers the entirety of benefits described in the concept of Industry 4.0. However, this integration is rarely seen due to different company functions having to exchange data with different underlying logic. As an example, this paper describes batteries of battery electric vehicles as a use case in which the integration across all three levels could unfold. Thereupon, the paper describes avenues for future research and managerial implications that highlight the need to collaborate across research disciplines and organizational functions alike.

Keywords: Industry 4.0, Industrial Internet of Things, Digital Transformation, Supply Chain Management, Supply Chain Collaboration
Introduction

Industry 4.0 offers the potential to revolutionize the value creation process of companies based on technologies like the Internet of Things and Cyber-Physical Systems that interconnect the real and virtual worlds. Further, horizontal and vertical integration across the entire supply chain, across different company functions, and across the entire product lifecycle shall be archived (Kagermann et al., 2013; Lasi et al., 2014).

However, the full potential of Industry 4.0 will only unfold if it is intelligently networked with upstream and downstream stages of the value chain. To this end, complete value-added chain systems or supply chains must be transferred instead of only being used within the boundaries of a company (Kagermann et al., 2013; Lasi et al., 2014; Veile et al., 2022). Although some of the underlying technologies, such as RFID, have been available since the 1980s, research on Industry 4.0 and its effects on supply chain management is still an emerging field of research (Ben-Daya et al., 2017; Veile et al., 2022).

As a result of Industry 4.0, several authors describe changes in supply chain design (Strange and Zucchella, 2017), such as the generation of manufacturing ecosystems (Benitez et al., 2020; Schmidt et al., 2021) or manufacturing reshoring (Dachs et al., 2019). While those developments are rather a result of Industry 4.0-induced changes in supply chain design, this paper aims to describe the effects of horizontal and vertical integration across the entire supply chain and across the entire lifecycle of products. This relates current research findings back to the original concept of Industry 4.0 as described in Kagermann et al. (2013) and Lasi et al. (2014).

Integration of product, production, and logistics levels in the concept of Industry 4.0

Overview

The paper first describes data exchange of logistics data across the entire supply chain tiers, which is the predominantly described form in research and practice. Subsequently, data exchange encompassing production and logistics levels offers even more potential but is also more challenging from a cross-organizational perspective (Schmidt et al., 2022). Finally, data exchange across production, product, and logistics levels offers the entirety of benefits described in the concept of Industry 4.0. However, this integration is rarely seen due to different company functions having to exchange data with different underlying logic (Müller et al., 2020).

Figure 1 below highlights the interconnection of product, logistics, and production levels. Most notably, different organizational functions must be interconnected – such as product lifecycle management (PLM) and innovation management on the product level, supply chain management on the logistics level, and operations management on the production level, among further.
Industry 4.0 implications for supply chain collaboration

Figure 1. Overview: Product, production, and logistics levels

Logistics level

Figure 3 below highlights the integration of logistics levels across the supply chain, the so far most commonly seen form of integration in many supply chains.

Figure 2. Integration of logistics levels

Data transferred in this regard could be stock, tracking of goods, delivery times, data from product status, and potential harms, among others. Thus, traditional logistics aspects, such as reducing the bullwhip effect or optimizing logistics routes, can be achieved (Schmidt et al., 2022).

The logistics levels of companies face the comparably highest level of interconnection already. Comparably, many SMEs still lack the capabilities to exchange data beyond logistics data with their supply chain partners (Estensoro et al., 2021; Lassnig et al., 2021).
Production and logistics level

Figure 3 below shows the integration of product and logistics levels across the supply chain.

Figure 3. Integration of production and logistics levels

Typical data exchanged could be Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP) data, or logistics data integration, such as the position and status of production facilities and products. The integration of production and logistics levels across the supply chain enables additional benefits, such as load balancing of manufacturing and logistics across the supply chain (Schmidt et al., 2022). However, companies are less willing to share data from manufacturing with supply chain partners than they are from logistics (Müller et al., 2020).

Product, production, and logistics levels

Figure 4 below illustrates product, production, and logistics integration across the supply chain.

Figure 4. Integration of product, production, and logistics levels
When adding the integration across the entire lifecycle of products, horizontal and vertical integration across the entire supply chain and product lifecycle in the sense of Kagermann et al. (2013) can be achieved. This relates back to the original concept of Industry 4.0, describing a potential "full scale" form of Industry 4.0 level. Figure 5 highlights this relationship.

![Figure 5. Horizontal and vertical integration across the supply chain](image)

If data is transferred across all three levels (product, production, and logistics), this requires data flow from product usage to product development and production. Potentials for sustainability include sustainable product design, recycling and replacement logistics, sustainable business models, or traceability of sustainable product features. Likewise, potentials for resilience include product optimization based on usage data, predictive maintenance and recycling, detection of failures and correlation with production and logistics parameters, prevention of downtimes, or shorter time-to-market (Schmidt et al., 2022; Veile et al., 2022).

This last form of integration encompasses the full potentials of Industry 4.0 relating to horizontal and vertical integration across the entire value chain and the entire lifecycle of products (Kagermann et al., 2013; Lasi et al., 2014). Notably, especially product data is critical to be shared across the entire supply chain due to feared knowledge loss and hard integrability, among other potential factors that impede its exchange (Müller et al., 2020).

Hence, trust and shared vision must be developed among other potential enablers of Industry 4.0 collaboration across all three levels described and across the entire supply chain (Müller et al., 2020; Schmidt et al., 2022). In particular, Small and Medium-Sized Enterprises (SMEs) must be integrated to share data and gain rewards from collaboration (Kazantsev et al., 2022). Conclusively, this might lead to a transformation of "traditional" supply chains towards manufacturing and innovation ecosystems in which companies collaborate mutually and with multiple connections to the end customer. This is in contrast to the current situation where mainly the Original Equipment Manufacturers (OEMs) have contact with the end customer and also gain the primary rewards of better supply chain collaboration and performance (Benitez et al., 2020; Schmidt et al., 2021). Via means of digital platforms and further technologies, Industry 4.0 can simultaneously act as a driver and enabler of this transformation. Hence, Industry 4.0 can be expected to transform supply chain collaboration and design and enable both in the first place (Schmidt et al., 2022).
Potential use case: Integration of battery production, logistics, and recycling in the lifecycle of battery electric vehicles

One example to display the above-described data exchange across production, product, and logistics levels is Battery electric vehicles (BEVs). Those require batteries representing a large proportion of the costs of the entire vehicle. Hence, supply chains of batteries should aim for a low number of batteries in storage while providing a sufficiently fast supply of batteries if those must be replaced (Pinske et al., 2014; Schindlbeck et al., 2020). Likewise, recycling of batteries poses a significant challenge for car manufacturers Recycling (Habib et al., 2020; Rajaefar et al., 2020).

Figure 1 below subsumes the above-described lifecycle of batteries in BEVs.

The integration of battery data across the value chain can be obtained from Figure 6. Batteries generate data in usage (product level) that can be transferred to production and logistics of new batteries. Likewise, data from batteries in usage can be used to develop future generations of batteries and optimize the recycling of batteries. Due to the high costs of batteries, the optimization of the battery supply chain as well as battery recycling can be enhanced using data from batteries in usage. For instance, temperature, distances travelled, charging behaviour, and further data can predict the requirement to change batteries. Further, if batteries can be partially replaced or must be fully replaced based on cell-specific data provides additional potential for optimization. Likewise, if batteries can be put to a second use, like in stationary batteries where decreased capacity is less of a problem or must be recycled, can be obtained from battery usage data.

Hence, batteries represent a case where data from product usage (product level) can be transferred to production and logistics processes of battery replacement, recycling, and second usage. This integration encompasses several supply chain tiers like automotive OEMs, suppliers, recycling providers, and repair workshops. Further, data from battery usage can be used to optimize future battery generations, highlighting the integration across the lifecycle of products from product development to product usage leading to product recycling.

Notably, the high price, energy consumption for production, and recycling requirements (Habib et al., 2020; Rajaefar et al., 2020) make batteries for BEVs a potential use case for "full scale" vertical and horizontal integration across the supply chain and product lifecycle as described in Kagermann et al. (2013).
Conclusion

Future research directions

This paper encourages research on the intersection of the different corporate and research domains described. While supply chain management and operations management have traditionally been integrated in both research and practice, especially the interconnection to PLM or innovation management across the entire supply chain remains scarce. This potentially objects the horizontal and vertical digital integration across the entire lifecycle of products as described in Kagermann et al. (2013).

In response, companies must enhance data exchange across the above-named functional levels (Müller et al., 2020). As this requires new forms of cooperation, trust and a shared vision of how this is achieved must be developed (Schmidt et al., 2022; Veile et al., 2022). In particular, SME collaboration and integration pose a challenge in this regard (Kazantsev et al., 2022). Hence, future research should address how data exchange can be established to benefit all supply chain partners and how suppliers, particularly SMEs, can be better integrated.

Another area for research is represented by future business models across logistics, production, and product levels and across the entire supply chain (Müller & Buliga, 2021). Hence, supply chains could transform into manufacturing and innovation ecosystems that integrate supply chain, operations, innovation, and further aspects (Benitez et al., 2020; Schmidt et al., 2021).

Finally, how the integration of product, production, and logistics levels can enhance sustainability by integrating product, supply chains, and operations configuration poses a future research direction (Lerman et al., 2022; Schilling & Seuring, 2023). The example of batteries for BEVs highlights potential future requirements in this regard (Habib et al., 2020; Rajaeifar et al., 2020).

Managerial implications

Several managerial implications can be derived based on the described contents and future research directions.

As highlighted in several instances in this paper, cross-departmental and cross-company collaboration must be enhanced in order to unlock the full potential of Industry 4.0. For instance, logistics is often understood as a cost-saving company function, while the product level is often related to innovation. Such different tasks and restrictions in various departments potentially object to innovation that spans beyond products but also to the supply chain, such as traceability features.

Likewise, cross-company data exchange often benefits the OEM but not the entire supply chain. Therefore, to leverage the full potential of Industry 4.0, innovation and products must be understood as a company-spanning and supply chain-spanning task. This task must integrate several supply chain stakeholders, providing benefits not only for the OEM but all suppliers that contribute to providing new products and innovation. Further, this also includes integrating SMEs better or new forms of supply chain-spanning business models. Subsequently, the transformation of supply chains through Industry 4.0 could lead to the required understanding of manufacturing and ecosystem business models.
References


