12-12-2023

The necessity of Industry 4.0 real-time big data applications – A comparison in different domains of industrial value creation

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Short Paper

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Abstract

Industry 4.0 is based on digital integration across entire supply chains, functional domains of industrial value creation, and from production to product use and recycling. Those three pillars refer to horizontal and vertical integration and end-to-end engineering. A further concept named repeatedly is real-time data availability and processing. However, research and industrial practice have shown that real-time data is even more complex to obtain than data in the first place, especially across entire supply chains. In response, the paper presents several examples highlighting cases favoring real-time big data applications. Further, opposite instances in which real-time data is complex to obtain or does not lead to sufficient benefits are presented. An overview is developed to subsume different settings, potentials, challenges, and requirements for real-time big data applications within the concept of Industry 4.0. Real-time applications are most important in production or human-machine interaction environments, whereas logistics processes or data relating to product development and recycling are far less relevant or achievable so far. Hence, the further from industrial production or non-critical processes, the harder it is to rectify real-time data collection. Further, especially supply-chain spanning data is hard to obtain in real-time quality.

Keywords: Industry 4.0, Industrial Internet of Things, Digital Transformation, Real-time Data Exchange, Information Sharing, Supply Chain Management

Introduction

The original concept of Industry 4.0 builds on digital integration across entire supply chains, functional domains of industrial value creation, and from production to product use and recycling (Kagermann et al., 2013). These characteristics refer to horizontal and vertical integration and end-to-end engineering. A further concept named repeatedly is real-time data availability and processing. However, research and industrial practice has shown that real-time data is even more complex to obtain than data in the first place, especially across entire supply chains and different data types (Ghouri et al., 2021; Ghouri and Mani, 2019; Müller et al., 2020; Schmidt et al., 2023; Winter et al., 2023).

Most extant publications that investigate real-time applications are related to scheduling (Darwish et al., 2021; Fernandez-Viagas and Framinan, 2022; Ghaleb et al., 2020), monitoring (Magadán et al., 2020), predictive maintenance (Einabadi et al., 2019) or performance management (Robert et al., 2022) processes. Further, applications relating to cloud computing (O'Donovan et al., 2019) or synchronous operation (Guo et al., 2021) are described.

However, most of those publications do not relate to the supply chain-spanning nature of Industry 4.0 (Kagermann et al., 2013) and the challenges of exchanging data and information across the supply chain (Ghouri et al., 2021; Ghouri and Mani, 2019; Müller et al., 2020; Schmidt et al., 2023; Winter et al., 2023). To understand the full potential of Industry 4.0 following horizontal and vertical integration through digital technologies (Kagermann et al., 2013), the topic of real-time big data applications should also be understood from a supply-chain-spanning perspective.

Hence, this paper aims to shed more light on where and how real-time big data applications are beneficial in the concept of Industry 4.0 and where those might not be required or non-beneficial so far. First, the paper relates to understanding the challenges of Industry 4.0 real-time big data applications regarding collecting and exchanging data across the supply chain as an impediment (Ghouri et al., 2021; Ghouri and Mani, 2019; Müller et al., 2020; Schmidt et al., 2023; Winter et al., 2023). Second, it aims to highlight the potentials of real-time big data applications that might value the efforts required, such as in data-driven business models in industrial applications (Müller and Buliga, 2019).

In the following, the paper compares product, production, and logistics levels regarding the challenges and potentials of real-time big data applications.

Real-time data exchange in different domains of Industrial Value Creation

Overview

In this paper, different domains of industrial value creation are compared: Product, production, and logistics levels, as well as their interconnection (Müller, 2022). This paper investigates the necessity of Industry 4.0 real-time big data applications in this context.

Figure 1 subsumes the product, production, and logistics levels referred to by Müller (2022) and the respective research disciplines: Product level (Product Lifecycle Management or PLM, Innovation Management), Logistics Level (Supply Chain Management), and Production Level (Operations Management).

This differentiation relates to the relatively already more feasible data collection and exchange in the supply chain on the logistics level compared to the production level (Müller et al., 2020) and potential differences on the product level.

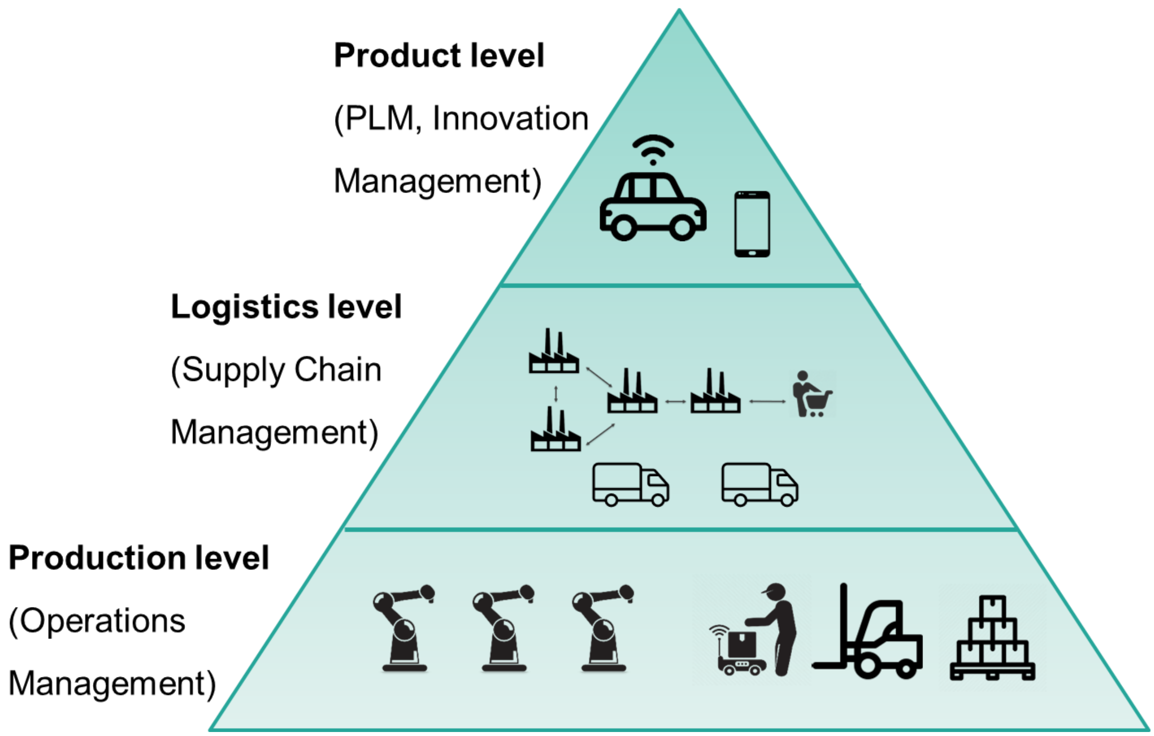

Figure 1. Overview: Product, production, and logistics levels (Müller, 2022)

In the following, the logistics level alone, its integration with the production level, and finally the integration of product, production, and logistics levels regarding real-time big data applications are described. This differentiation is chosen since Industry 4.0 tries to integrate production, logistics, and product levels in a way that integrates all of those across one company and the entire value chain using digital technologies (Kagermann et al., 2013).

Real-time data exchange between production and logistics levels

Data and information to be exchanged at the logistics level include inventory, tracking, delivery times, or product status. This data is easy to transfer and is already transferred a lot today. Further, suppliers are comparably willing to share this kind of information with their customers due to little sensibility of data (Müller et al., 2020).

There are several examples where it makes sense to exchange data between production and logistics levels in a way that refers to real-time applications. For instance, if a truck is rerouted to somewhere based on current events, this has to happen quickly, preferably in real-time. This is also probably why the majority of extant publications on real-time big data applications in the context of Industry 4.0 focus on scheduling activities (Darwish et al., 2021; Fernandez-Viagas and Framinan, 2022; Ghaleb et al., 2020). Still, it remains questionable if real-time data is required for this task or if a certain time delay can be allowed since logistics processes act as a certain time delay themselves in contrast to production processes, as discussed below. Further, real-time data makes sense if something goes wrong, leading to damages or failures, thus immediately avoiding production problems.

To give another example, other processes like inventory are questionable regarding real-time applications in the current state because it will take some time to establish this, especially across the supply chain. Hence, inventories could have a certain delay since they act as a natural temporal buffer, and ordering is typically organized in batches, not in single products.

However, if the aim is to connect to a company’s suppliers and also to its customers, it will be even harder to get real-time data. First, there will be several technical issues simply because a lot of data could be transferred (Müller et al. 2020). Hence, a company should filter it in some way pre-select data because sharing all of this data and getting it back to suppliers and customers in real-time requires large efforts across the supply chain with such a large amount of production data. Hence, it is vital to choose the processes that make sense carefully, and other ones could require filtered data, differentiating between real-time data and data that will be evaluated later.

Real-time data exchange between product, production, and logistics levels

If all three levels, i.e., product, production, and logistics, are interconnected, obtaining and exchanging the correct data and information is even more complicated. Hence, it is required to filter and pre-select the processes where it makes sense and where it doesn't make sense to establish real-time big data applications.

For instance, if the goal is to transfer data from product usage to product development and production, this makes sense in specific critical processes. However, for example, product development is an area that doesn’t need real-time data yet. This is, for instance, as developing and testing take some time, which allows time delays between data collection and putting data to use. The same applies to recycling products where real-time data exchange might not yet be required, as data from product usage can be collected and stored, allowing recycling at the right point in time (Rahman et al., 2020).

Hence, there are different domains where it makes more sense and others where it makes less sense to establish real-time big data applications when integrating product, production, and logistics levels. For example, sustainable product design with real-time improvements during product usage is a domain that could be reasonably built on real-time data. Such an approach could be based on “over the air” software updates that react to new requirements in real time. Especially if a particular business model that fits the proper provision of data in real-time meets customer expectations to also monetize such an added value (Buliga and Müller, 2019), it makes sense to implement this in real-time.

Further, detection of failures, which, again, depends on the product, might take more time to have real-time data to prevent failures and damages directly. However, as also discussed in the next section, it will be hard to get some of the data since suppliers do not have direct contact with end customers and vice versa (Müller et al., 2020; Schmidt et al., 2023). Further, often, suppliers do not even know each other and thus cannot exchange data and information, which is a prerequisite of Industry 4.0 to exchange this data (Kazantsev et al., 2023).

Finally, if, for example, an autonomous car is communicating while driving, it makes sense to have real-time data if the vehicle will react in real-time on the road. However, this does not necessarily require real-time data flow from the product to production or logistics. Notably, it is comparably harder to have real-time data flow from products back to a company’s production and logistics, especially with suppliers. This is simply due to the enormous amount of data that has to be shared all across the supply chain.

Challenges of real-time data exchange on product, production, and logistics levels

While data exchange and information transparency alone pose several challenges to be established (Kanyoma et al., 2018; Kembro et al., 2017), real-time data is even more complex to obtain and exchange, especially critical data types (Müller et al., 20202; Schmidt et al., 2023). There are several reasons for this, which are further discussed below.

First, existing data standards vary across product, production, and logistics levels. The same applies to the potential issues of trust and confidentially and, thus, limited willingness to share data and information (Müller, 2022; Schmidt et al., 2023; Winter et al., 2023).

Second, small and medium-sized enterprises (SMEs) are not easily integrated as well as second-tier or third-tier suppliers or suppliers further down the supply chain (Kanyoma et al., 2018; Kazantsev et al., 2023; Kembro et al., 2017), In particular, SMEs face difficulties regarding data and information sharing as well as multi-tier supply chain management facing issues of trust, understanding, and limited resources alongside bargaining power due to their size (Winter et al., 2023).

Third, there is little transparency regarding the requirements of data exchange and information sharing (Schmidt et al., 2023). Acting as a central enabler for industrial ecosystems, such an approach requires decentralized orchestration and enhanced trust to overcome reluctance to share data and information (Kazantsev et al., 2023).

Fourth, in many cases, the customer is willing to pay for a specific solution, but those solutions have to be implemented at the supplier, not at the OEM. So the direct supplier gets the money, but it's not where the real-time data required potentially comes from. Hence, the adequate business model must coincide with adequate business models (Müller and Buliga, 2019).

Conclusively, Figure 2 below gives an overview of potential challenges across the supply chain as well as between different suppliers on the same supply chain tier level, illustrating several examples.

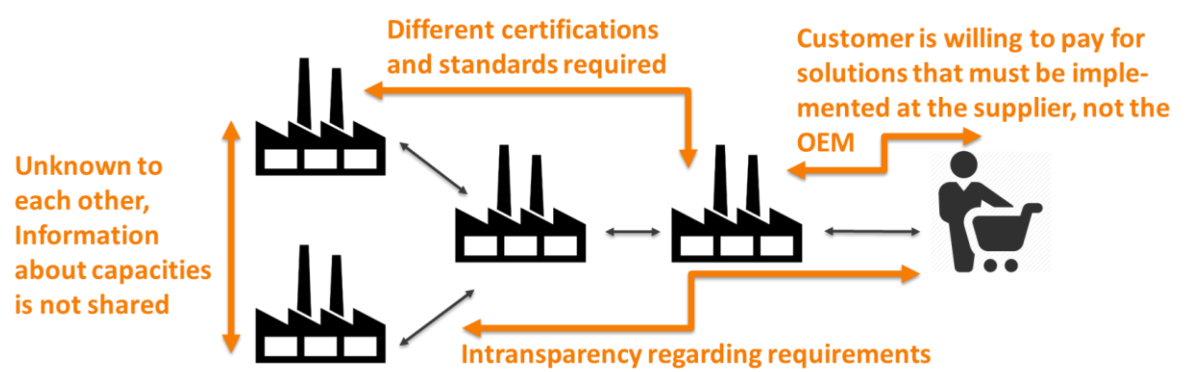

Figure 2. Challenges of data exchange across the supply chain

Conclusion

Managerial implications

Several managerial implications can be derived from this paper's contents and the directions for future research presented below.

First, it is vital for managerial practice to determine which data is relevant to obtain in real-time and which data might be feasible to obtain on a quality level with a specific time delay. Hence, the efforts to collect and synchronize data should only be prioritized if presenting a benefit. This relates to the second managerial implication given below.

Second, the interconnection of different data sources, data types, and data qualities to achieve which kind of benefit, such as a new business model, must be understood. Hence, only if a customer benefit is generated that customers are also willing to pay for should real-time data exchange be implemented

Third, managerial practice must understand how to obtain this data, especially across their entire supply chain or from products to which they are not the original equipment manufacturer and thus have limited access so far. Hence, besides the two rather strategic decisions or understandings required, the third managerial implication relates to a technical understanding.

Future research directions

The paper connects the topic of real-time data applications with industrial practice and requirements, therefore allowing the merging of the views of big data disciplines with industrial requirements. While only presenting a first overview and conceptualization, several implications for future research are stated below to spark further research.

First, ecosystems, or industrial ecosystems, require data exchange and information transparency across several supply chain tiers and in the same supply chain tier level, i.e., among suppliers (Kazantsev et al., 2023). Both have hardly been established so far (Kanyoma et al., 2018; Kembro et al., 2017) and thus require future attention on how to integrate real-time data across the supply chain and across different supply chain tier levels.

Second, digital platforms act as an enabler of data exchange and thus increase transparency (Schmidt et al., 2019). Likewise, digital platforms enable industrial ecosystems to facilitate multi-tier supply chain data exchange and information sharing on the same supply chain tier level (Kazantsev et al., 2023). Hence, the role of digital platforms for real-time applications should be investigated in future research, in particular in conjunction with enabling industrial ecosystems.

Third, recycling data and information is required to be shared and combined with further data to achieve the concept of a Circular Economy (Rahman et al., 2020). Here, the question of real-time feasibility arises, especially if adequate applications require a real-time approach. For instance, since recycling might be a process later in time that is not too time-critical, the question of adequate real-time big data applications arises.

Fourth, business models that arise from real-time big data applications represent an interesting area for future research (Müller & Buliga, 2019). Likewise, it is of particular value to understand the impediments to establishing such business models (Witschel et al., 2023). Hence, as also described in the managerial implications, understanding feasible business models for real-time big data applications must understand

Fifth, only industrial data was concerned so far in points one to four above, especially regarding product data from usage. Further data, such as social media data, could present valuable insights if collected from both product levels, i.e., from end customers, and social media data from where those products were manufactured, i.e., business-to-business social media data (Birkel and Müller, 2022). Especially in this context, it is vital to understand how different data sources from different domains can be combined and where real-time applications represent a fruitful overall concept.

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