3rd Conference on Production Systems and Logistics

Openness Of Digital Twins In Logistics – A Review

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Abstract

Openness is becoming increasingly important in scientific research and practice. It describes the phenomenon of sharing information with other internal or external stakeholders by using different technologies, e.g., cloud computing, distributed ledger, or digital twins. Hence, many researchers investigate and evaluate the openness of platforms. Alongside these platforms, digital twins are gaining influence in industrial processes. A digital twin is a virtual representation of a physical entity connected through a bi-directional data linkage. Its primary purpose is to visualize, analyze, and optimize production and logistics systems. Nevertheless, research shows a lack of knowledge in the domain of the openness of digital twins and that the topic has not been addressed adequately. To approach this research gap, this paper provides a review of literature-based work on digital twins focusing on logistical contexts. It aims to answer the question of how open digital twins are, depending on their use case, purpose, and status as digital twin or digital shadow. Through a comprehensive research approach, this paper provides researchers and practitioners with meaningful insights into the openness of digital twins.

Keywords

Openness; Digital Twin; Production and Logistics; Review

1. Introduction

It was inconceivable to make internal operations transparent to external stakeholders for decades. Even within a supply chain, each company operated within its premises. But transparency along a supply chain holds many advantages for logistics because logistics connects places and companies in global networks and creates value [1]. Therefore, the aspect of openness has become increasingly important, especially in research. Openness results from transparency, which in turn is created by the exchange of data between different entities [2]. This data exchange is supported, among other things, by a so-called digital twin. The digital twin is a virtual construct of an actual entity with a bidirectional connection [3]. It is this connection that enables new applications. Following [4], the interest in the digital twin has increased in research and industry. Many companies see great potential in using the digital twin [2], so it will gain further influence on industrial operations in the future. One of the primary purposes of a digital twin is to create transparency in logistics by solving problems regarding visibility [5]. Nevertheless, as with many digital constructs, e.g., virtual platforms, data sharing is often limited by user requirements, data sovereignty of owners, as well as suppliers [6]. At this point, the following research question arises:

RQ1: Are digital twins enabling data sharing within ecosystems?

DOI: https://doi.org/10.15488/12186 publish-Ing.

Before research may address the level of openness, we must ensure that digital twins, in principle, can provide transparency through data sharing. Then, if data sharing capability is guaranteed, we examine the level of openness of digital twins for data sharing. Thus, the second research question reads as follows:

RQ2: How open are digital twins used in logistics?

To answer the research questions, we conduct an exploratory examination of the topic area based on a systematic literature review following [7] as well as [8]. The paper is structured as follows. First, we provide insight into the concepts of digital twins, their data sharing capabilities, and the general concept of openness. Then, we give an overview of the research method before we describe the literature review results. After that, we explain and discuss our observations. Finally, we summarize the findings and offer contributions, limitations, and an outlook for further research topics.

2. State of the Art

2.1 Digital Twins

Digital twins originate from the decades-old concept of physical twins as simulation and experiment environments for real-world applications [4]. One of the first noted deployments was the Apollo Space Project, in which physical twins mirrored the space capsules for testing purposes. Since then, the concept of digital twins has developed continuously. Starting from [3], who defined the digital twin as a combination of physical and virtual products that are connected by data and information. Later, [9] extended their view as they now see sensors as the primary data source for digital twins. They laid the ground for the digital twin as a concept for product life cycle management [10].

Simultaneously, NASA pushed digital twin concepts further. Researchers from this ecosystem see the digital twin as "an integrated multiphysics, multiscale, probabilistic simulation" [11, p.7]. This paves the way for the second research stream in which the digital twin is seen as the current development stage of the classical simulation of production and logistic processes [4]. Both research streams combine the fact that they lack a fundamental understanding of what a digital twin consists of [12]. In the last two years, extensive research and work have tackled this research gap. [13] concentrate on the data flows towards and from a digital twin to specify the concept. They demand a bi-directional data flow for digital twins as the distinguishing feature between digital twins and digital shadows as well as digital models. [14] extends the digital twin by the dimension of services and examines the question of what a digital twin should be able of in hindsight to data processing. A more thorough analysis was the creation of a taxonomy of digital twins, which describes the digital twin in the eight dimensions data link, purpose, conceptual elements, accuracy, interfaces, synchronization, data input, and time of creation [15]. [16] come to similar but more nuanced dimensions with their twelve characteristics and extend the eight dimensions with the aspects of physical and environment, fidelity, and system state. The latest development is five archetypes of digital twins, ranging from a basic twin with low capabilities to a fully enhanced digital twin that can process complex operations and monitor and control physical systems [17]. From this research, we follow the most recent and concluding definition: "The digital twin is a virtual construct that represents a physical counterpart, integrates several data inputs with the aim of data handling, data storing, and data processing, and provides an automatic, bi-directional data linkage between the virtual world and the physical one. Synchronization is crucial to the digital twin to display any changes in the state of the physical object. Additionally, a digital twin must comply with data governance rules and must provide interoperability with other systems" [17, p. 14]. Especially, the new and not yet in combination with digital twins portrayed dimensions of data governance and interoperability are crucial for this paper. Data governance may consist of many rules, but it is not specified which rules should apply. For interoperability, three configurations are provided by [17]. There is either no interoperability, a certain degree of interoperability via translation devices within the interfaces, or full interoperability between all agents within a given ecosystem. We assume a high level of openness for a fully interoperable digital twin, which we will analyze in this paper. A related concept to digital twins is the concept of digital shadows. In this paper, we follow the differentiation of [13]. Hence, a digital shadow shows many aspects and properties of a digital twin but lacks a bi-directional, automatic data flow.

[18] have investigated the use of the digital twin and provide an overview of the industries in which digital twins are used. Here, the Digital Twin supports simulation, monitoring as well as optimization of the physical plant [18,15].

2.2 Openness

The term *openness* describes the way technologies are used concerning exchanges with other stakeholders. The focus here is on the use of technology [19]. According to [20], openness is achieved through collaboration between different actors. It is possible that organizational boundaries may limit the actors. Thus, it is unnecessary to share the technology with external stakeholders to operate “open”. Thereby, transparency is one prerequisite for openness [21]. The challenge is to find the right balance between control and openness [22–25]. One challenge, for example, is to create governance rules that appropriately limit participants' freedom of action [22]. Therefore, [19] sort openness into different degrees. Closed technologies have the smallest degree of openness. Only one actor controls them. Usually, the access for other actors is restricted by the owner through, e.g., the imposition of patents or copyrights [19,26]. Opposing technologies are those that are used to be purely open. They are accessible to all actors [19]. Between both extremes are many levels of openness, which depend on individual use cases.

The combination of openness and information technologies generates opportunities. Information technologies enable a broad scope of open practices such as open source, open source software, and open innovation [27]. Open source is often used in the field of programming. The idea is to unify the efforts of programmers. Sharing the code or granting access to the code are essential parts of being open source in programming. The term is based on open source software [28,29]. The unique feature of the open source software is that a comprehensive group of users has access to the software's source code. Furthermore, they are allowed to use and to modify the software. These changes give rise to further artifacts, which in turn can be distributed.

In recent years, the term *open innovation* achieved a lot of attention. Open innovation describes the necessity to access a technology and concentrate on an open research and development process [30]. [31] has developed six principles regarding open innovation. Among other things, he assumes that it is crucial to use the expertise and experience of external parties. This extern research and development create an added value that could be useable for the intern analysis. The optimum will be achieved by combining the intern and the extern research and development. Since there are several definitions of the term open innovation, [32] defines it newly. According to him, open innovation is a distributed innovation process. The basis of this process is a consortium of precisely controlled knowledge flows. These go beyond the boundaries of the company. These knowledge flows are used in a targeted manner in line with the business model.

3. Research Method

The aim is to analyze the digital twin in logistics in terms of its openness. For this reason, the research method starts with a structured literature analysis according to [7] and [8] to obtain an overview of existing literature. Thus, the first step is the database search. Therefore, the search string has been defined. The search should focus on the digital twin, which results in the first part of the string *"Digital Twin"*. Furthermore, the search is to be restricted to the domain of logistics. Since in English, the terms "logistics" and "supply chain" are sometimes used as synonyms, the second part of the search string *("Logistics" OR "Supply Chain")* results. The subject area of openness is not specifically narrowed down at this point. Some publications describe the construct of openness but do not explicitly call it openness. The search result confirms this statement (see [33,34]). The entire search string reads as follows *"Digital Twin" AND ("Logistics" OR "Supply Chain")*. This has been entered into five common databases (AISeL, IEEEXplore, WoS, Scopus, and Science Direct). To make possible developments of the digital twin visible, the search has not been restricted to a publication period. Also, to obtain a high-quality literature review, the search has been limited to peer-reviewed papers. Additionally, only papers in English have been included. The period in which the search has been carried out extends through winter 2021/2022.

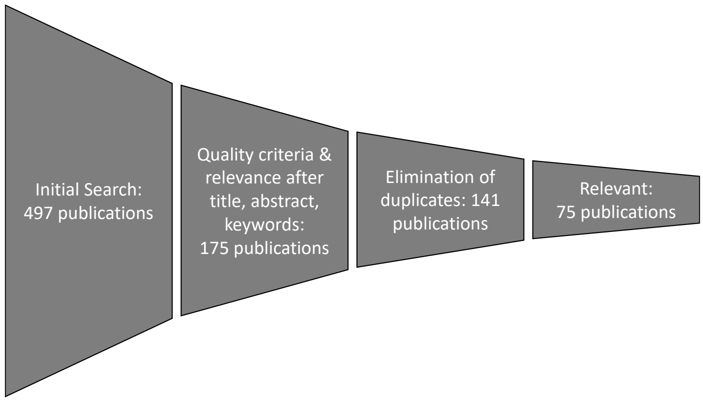

Figure 1: Search Process.

The search, including forward and backward searches, resulted in 497 publications (see Figure 1), of which 175 were declared relevant after an analysis of title, abstract, and keywords and the application of the quality criteria. As quality criteria, we demanded a peer-review process, a sound description of the research process, the application of commonly accepted research methods, and a noticeable consistency throughout the paper. The extraction of duplicates resulted in a literature sample of 141 publications. These were entirely analyzed by the two authors and then included in the final literature sample according to their relevance. The final sample consists of 75 publications.

4. Openness of Digital Twins

To answer how open digital twins are, we first have to ensure the overall capability of a digital twin to be open (see RQ1). We define a concept as being able to be open if it can provide transparency over a process. [17] state that the two most important purposes of a digital twin are simulation and monitoring. Deriving from there, we may expect the capability to provide transparency. In fact, monitoring any process will bring transparency to the monitored process. Additionally, simulation operations offer an overview of a particular system and provide transparency. [35] even developed an architectural model for digital twins primarily used to create transparency in supply chains based on the International Data Spaces and their connectors. As operational digital twins in production and construction already exist (e.g., [36], [37]), which create transparency, we attest to the digital twin`s ability to create transparency.

This leads to the second research question, how open are digital twins in logistics. During the analysis, we could identify three classifications of openness: intraorganizational, dual, and multisided. If the digital twin is just implemented within one participant of the supply chain, we allocate the digital twin to the label intraorganizational. There is no exchange of information between different participants of the supply chain via the digital twin. If the digital twin is shared with only one other participant in the supply chain, we label the digital twin as dual. The third label is called multisided. This label describes the implementation of the digital twin by more than one participant of the logistical network. Data and information are shared within this ecosystem. These three classes align with the postulation that there are different degrees of openness (see section 2).

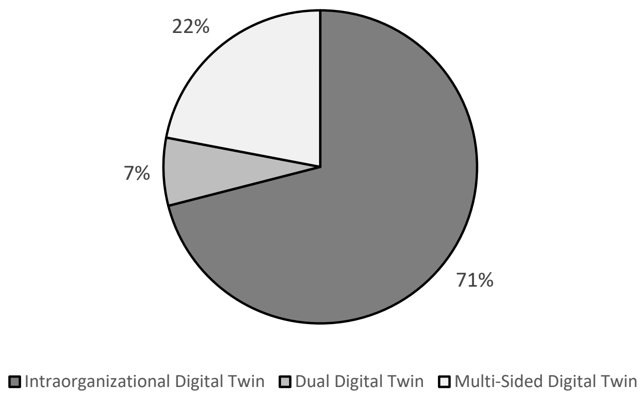

Figure 2: Shares of Openness.

An analysis of our concept matrix shows that 71% of the articles describe the implementation of the digital twin within just one participant (see Figure 2). The other 29% percent are split between dual (7%) and multisided (22%). This result contradicts our expectations that the participating enterprises share the digital twin within the entire supply chain. An explanation for this is that enterprises may see risks regarding data security, governance, or data abuse [38]. Therefore, they use the digital twin primarily within their own enterprise.

To gain a deeper insight, we specify the analysis and search for relationships between the openness and other categories like use case, purpose, and twin type. The use case is based on the established Supply Chain Operations Reference Model (SCOR Model). This model is used for standardizing the processes in a supply chain. It consists of the five different operational phases: plan, source, make, deliver, and return [39]. Additionally, we note that digital twins have three primary logistics purposes: simulation, optimization, and monitoring [17]. Furthermore, there are two twin types, digital twin and digital shadow, which are explained in section 2.1. Table 1 visualizes the results.

Table 1: Correlations Openness (max. values highlighted).

Meta-Dimension	Dimension*	Intraorganizational	Dual	Multisided
Use Case	Plan	18%	17%	11%
	Source	7%	**33%**	11%
	Make	**61%**	25%	22%
	Deliver	12%	25%	**49%**
	Return	2%	0%	7%
Purpose	Simulation	**46%**	28%	**52%**
	Optimization	26%	**43%**	16%
	Monitoring	28%	29%	32%
Twin Type	Digital Twin	**83%**	**67%**	**85%**
	Digital Shadow	17%	33%	15%

*Each object may address multiple dimensions within one meta-dimension. However, only the primary dimension is noted.

Due to space limitations, we have not included the conceptual matrix with all 75 publications in this paper. The results show some interesting insights. Starting with the use cases, we notice different distributions between the level of openness. Intraorganizational digital twins show the most significant variations between the extreme values. Sixty-one percent of the analyzed digital twins are mainly operated in the make phase. Hence, this is the most common relation. As the make phase is often within one enterprise, the usage of intraorganizational twin is plausible. In these cases, the digital twin is mainly used to simulate and optimize the enterprise's own material flow and not the entire supply chain. On the contrary, just two percent of the digital twins are used within the return phase. These cases often include the former customer and an external return company. The manufacturer is mostly not integrated into these processes. Hence, intraorganizational twins are demanding, as this is a highly transactional business that includes at least three parties (manufacturer, customer, and return company).

Dual twins are most common in the phase source, in which bilateral relationships between manufacturer and supplier are common. Though, make and deliver are essential phases for dual twins as well. Whereas multisided digital twins are concentrated on the deliver phase. This is no surprise, as a manufacturer naturally delivers its products to many customers who need access to the digital twin. That nearly one-quarter of the dual and multisided digital twins are used in the make phase shows the potential of the more open twins. The production processes are more and more intertwined with other factories and companies. Hence, a digital representation, which follows this exchange level, needs to be in place.

The main benefit of a digital twin is the possibility of simulation [40]. So, it poses no surprise that many digital twins for simulation purposes are intraorganizational twins. However, it is surprising that the dual twins` primary purpose is optimization. Often these twins optimize logistics flows between two companies. So, these two companies are forced to share data. Nevertheless, often they do not want to integrate further participants. Hence, multisided twins are not so common in optimization.

These multisided digital twins are more often used for visibility, monitoring, and simulation purposes. Visibility is justified by the aim of transparency across the entire supply chain. Hence, data from various suppliers need to be integrated. Similarly, simulation gets better as the amount of data increases. So, it is reasonable that the consolidation of data from different enterprises supports the simulation. As expected, most analyzed objects describe true digital twins. The intraorganizational and multisided digital twins are mostly true twins, as the commonly related twin type is the digital twin. However, many so-called dual digital twins are digital shadows (33%), following the definition of [13]. Hence, the digital shadow is common when shared with other enterprises. As mentioned, enterprises see risks in sharing their data with other enterprises. Through the manual data return flow provided by a digital shadow, the enterprise can influence the quantity of the shared data. Using a digital twin will lose this influence because the digital twin shares the data automatically with the other enterprises. In addition, the automatic data return flow could directly influence the enterprise's productivity when the other enterprise performs changes via the digital twin.

5. Conclusion and Outlook

This paper reviews the levels of openness of digital twins in the domain of logistics. Therefore, we analyzed the literature through a structured literature review. Regarding RQ1, we state that digital twins are per se able for interorganizational data sharing. They are able to create transparency over a process. Hence, digital twins provide the basics and fundamental capabilities to be considered open. For RQ2, the review gives us a deeper look at the openness of digital twins in logistics. The results show that combining the topics of digital twin and openness opens a new field of research.

Regarding openness, the focus on intraorganizational digital twins is rather astonishing. This result contradicts our expectations that the participating enterprises share the digital twin within an entire supply chain. An explanation for this is that enterprises may see risks regarding data security, data governance, or data abuse. Through the manual data return flow, which is provided by a digital shadow, the participants have the possibility to influence the quantity of the shared data. If they use a digital twin, they may lose this influence because the digital twin should share the data automatically with other participants. In addition, the automatic data return flow could directly influence the participant's productivity when another participant performs changes via the digital twin. Therefore, they use the digital twin primarily within their own enterprise. At this point, a research gap arises since openness is an important topic in logistics. Hence, a certain level of visibility is justified by the aim of transparency across the entire supply chain. Concluding the discussion, we identify several research gaps that should be investigated in further research:

- Focus on the openness of digital twins in practice
- Providing reference architecture and standard procedures for data security in open digital twins
- Description of industrial applications and use cases
- Focus on additional domains besides classical logistics

Our work is subject to certain limitations. Even if we tried to keep any subjective influence to a minimum, the classification naturally suffers subjective influences. In particular, other researchers may make the distinction between digital twins and the evaluation of openness differently. Therefore, they obtain different results. However, this research makes multiple contributions to the corps of scientific research, as well as managerial contributions. We structure the literature on digital twins in logistics and visualize certain conclusions regarding the openness of digital twins. These conclusions provide white spots that are suitable for further research. Hence, new research streams may be implemented upon this paper. The managerial contributions are not quite as direct as the scientific ones. Digital twins still lack a broad operation base in logistics contexts. Nevertheless, we provide the industrial experts with the prerequisite for a deeper look at their projects regarding open digital objects that accompany their logistics. Furthermore, practitioners will benefit from future research on this topic.

Acknowledgements

This research was conducted in the project "Silicon Economy Logistics Ecosystem" and is funded by the German Federal Ministry of Transport and Digital Infrastructure.

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Biography

Stephanie Winkelmann (*1994) has been a researcher at the Chair for Industrial Information Management at the TU Dortmund University since 2022. She has graduated with a Bachelor's degree in Business Administration and Logistics and holds a Master of Science in Logistics from TU Dortmund University. In cooperation with the Fraunhofer Institute for Software and Systems Engineering and the Fraunhofer Institut for Material Flows and Logistics, she conducts her research as a member of the Silicon Economy.

Hendrik van der Valk (*1992) has been a researcher at the Chair for Industrial Information Management at the TU Dortmund University since 2019. He studied Mechanical Engineering, and his research focuses on Digital Twins in production and logistics. He conducts his research as a member of the Excellence Center for Logistics and IT and the Silicon Economy. He is currently a member of the Association for Information Systems AIS and the Institute for Operations Research and the Management Sciences INFORMS.