3rd Conference on Production Systems and Logistics

Practical Requirements For Digital Twins In Production And Logistics

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Abstract

Companies are under tremendous pressure to analyze and optimize their productional and logistical networks in today's global business world. Hence, practitioners and researchers show great interest in digital twins. A digital twin is a virtual construct that mirrors real-world objects and conceptual ideas while it processes, handles, distributes, and optimizes data streams. Its main purpose is to visualize, analyze, and optimize objects and systems, making a digital twin highly suitable to help companies gain an advantage over their competitors through a great degree of transparency over their production and logistics. Therefore, almost every company evaluates the usage of digital twins. Nevertheless, many companies struggle to instantiate digital twins since they lack fundamental knowledge about all necessary components of a digital twin and the individual requirements for the operation of the digital twin. This lack of knowledge hinders the broad implementation in practice. Research shows many descriptions of theoretical use cases and field studies but rarely describes digital twins in real operational settings. To address this research gap between theoretical concepts and practical challenges of the implementation of digital twins, this paper investigates the practical requirements of digital twins in real-life usage. Based on a thorough interview series with international manufacturing and logistics experts, we identify and analyze the requirements for data handling, data policy, and services of digital twins and cluster them according to the requirements engineering approach. Through a comprehensive overview of the different requirements, the paper delivers profound insights into the needs of companies from various fields and, therefore, gives practitioners a guideline on crucial aspects of implementing digital twins.

Keywords

Digital Twins; Production; Logistics; Practical Requirements; Interview Study

1. Introduction

Modern global business environments face significant pressure to perform in a holistic analyzed, and optimized setting. This mainly includes production as well as logistics networks. Hence, a thorough search for digital tools helping with the optimization processes has started. A promising tool for these tasks is the digital twin. Thus, practitioners and researchers are interested in digital twins [1,2]. A digital twin mirrors physical counterparts, processes data, and provides the opportunity to create optimized processes [3]. Significantly, the digital twin`s primary purposes, including visualization, analysis, and optimization of objects and systems, provide appropriate resources for companies to gain an advantage over their competitors by providing a high level of visibility into their production and logistics [4]. As a result, almost every company is evaluating the use of digital twins [5,6].

However, due to the significant gap between scientific research and practical knowledge, companies still struggle to implement digital twins suitable for real-world applications. Of considerable relevance are the topics of the necessary components of a digital twin and the individual requirements for operating the digital twin. This lack of knowledge blocks widespread implementation in practice leading to the following research questions:

RQ1: What are the individual requirements for digital twins in production and logistics?

To bridge the gap between scientific knowledge and practical implementation, users need to know the individual requirements. To gain an industry-focused result, we aim at a practice-oriented approach for gathering requirements for digital twins. Based on these particular requirements, we can derive a broader framework leading to the second research question:

RQ2: What are the fields of interest /categories for practitioners concerning the requirements for a digital twin?

From these synthesized requirements, modules and clusters bring further order to the field of knowledge. We expect multiple insights from interviews with industrial experts. However, as only few companies have implemented a digital twin, we must wonder whether the industry is ready to tackle the topic of digital twins:

RQ3: Is it worthwhile to have a closer look at the practical requirements of digital twins?

Knowledge about the requirements of a specific object permits further scientific artifacts, which may enable practitioners to implement more of these artifacts. Together with the question of whether the practitioners are ready for implementation, we pave the way for further practice-oriented research.

The paper is structured as follows. The following section provides the basics about digital twins, after which we outline the research approach. In section four, we discuss the results and outline the different requirements. Finally, we conclude the paper and provide the contributions, limitations, and further research possibilities.

2. Theoretical Background

Starting from physical twins that have been applied in production for decades [7], the concept of digital twins constantly evolves [2]. The original digital twin concept stems back to a lecture by Michael Grieves describing a digital twin as a three-part concept [8]. According to Grieves, a digital twin contains a physical product, a virtual product, and a bi-directional data flow between both products. This description was expanded by two additional elements, including sensor data and historical data sets at a later point [3]. [9] provides further relevant insights into digital twins, defining digital twins as an extension of digital models and distinguishing digital twins from digital shadows through the type of data linkage since digital twins possess a bi-directional data linkage to their physical counterparts. Furthermore, [10] describe the data handling methods of a digital twin and focus their work on the service domain of a digital twin. [2] and [11] provide more specific descriptions of digital twins. The former describes eight different dimensions of a digital twin: data link, purpose, conceptual elements, accuracy, interfaces, synchronization, data input, and time of creation [2]. The latter describes similar dimensions. Nevertheless, they add the dimensions physically, environment, fidelity, and state of the system [11].

[4] provide a combination of the above developments and define five archetypes of digital twins. The following definition forms the basic understanding of digital twins in this contribution:

> "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" [4, p. 14].

Requirements for digital twins are seldomly examined. A comparison within the common databases shows that less than one percent of the literature on digital twins deals with requirements for digital twins [12]. The current works are either literature reviews (e.g., [13] or [14]) or focus on specific domains, mainly in the context of manufacturing (e.g., [15] or [16]). Commonly listed aspects are a bi-directional data linkage, specific interfaces (HMI and M2M), or real-time capabilities. Many requirements, however, may be directly synthesized from the given definitions. Therefore, we aim for a more practical approach and capture the requirements from real-world applications.

3. Research Approach

Requirements engineering is a methodology for defining requirements for a technical system or a technology such as the digital twin [17]. In this context, requirements are properties that technology needs to possess. These requirements can also be framework conditions under which the technology must perform [18]. According to [19], requirements engineering consists of the four steps identification, analysis, specification, and validation.

First, the requirements must be identified by analyzing existing systems or conducting interviews with selected experts. This leads to a plethora of unsorted requirements (step 1). We chose an empirical approach and conducted several interviews (see Table 1). This paper presents research in progress and, hence, we started with a small sample of six interviews, three with experts from logistics and three with experts from productional contexts. Another goal of this study is to evaluate whether more in-depth research with an extended interview series is appropriate. Hence, further interviews will follow.

Table 1: Sectors and Company Sizes of the Interviewees

#	Sector	Company Size
1	Logistics	>50,000 employees
2	Production	>80,000 employees
3	Production	>20,000 employees
4	Production	>7,000 employees
5	Logistics	>100,000 employees
6	Logistics	>50,000 employees

The interviews follow the approach of [20]. The starting point is the identification of the interview partners. All six interviewees are experts with many years of experience in their respective fields of work. The mixture of the interviewees provides a balanced picture of different domains, i.e., logistics and production. The interviews followed a semi-structured approach, as we did not prescribe many questions but aimed for a free conversation and just provided the interviewee with thematic blocks [21]. To identify the necessary expertise of the interviewee, we first asked introductory comprehension questions regarding digital twins. Nevertheless, following the advice of [21] and [22], we ensured combability between the individual discussions through minor guidance if an interviewee digressed from the core of the discussion, the requirements. All interviews were recorded and transcribed.

During the analysis's second step, we sorted the requirements into groups. These groups contain requirements, which show relations amongst them. One way to analyze is to differentiate between functional and non-functional requirements. According to [17], functional requirements define what is to be executed by a technology. On the other hand, non-functional requirements describe how the technology should function. Another task of the analysis is the elimination of identified redundancies, and lastly, the prioritization of the requirements (step 2). During the specification phase (step 3), we streamline the formatting of the requirements. We furthermore performed both steps simultaneously and listed all requirements chronologically. Then, we coded each requirement to gain comparability between the requirements. In addition, it allowed us to identify and synthesize duplicates. In total, the interviews provided 30 individual requirements. After the analysis and specification, eight distinctive requirements were left. Finally, there is a validation of the requirements by comparing the requirements with the stakeholders' expectations (step 4).

4. Requirements for Digital Twins

The eight distinctive requirements deal with different aspects of a digital twin, i.e., data handling, data policies, or digital twin services (DT Services). Table 2 provides an overview of the requirements.

Table 2: Derived Requirements

RQM	Requirement	Category
1	Synchronization between digital and physical parts must be reliable	Data Handling
2	Data sovereignty / Control over which data is exchanged and for how long	Data Policies
3	Data security, data protection, and data governance rules must be implied	Data Policies
4	Role allocation for digital twins through neutral standard access rules	Data Policies
5	A digital twin must possess real-time monitoring and data analytics	DT Services
6	A digital twin must possess simulation and prediction tools	DT Services
7	Data sharing capabilities and interfaces for data sharing must be present	Data Handling
8	A digital twin must be (at least) semi-automated	Data Handling

4.1 Requirement 1: Synchronization

Three out of six interviews demand specifically a reliable synchronization between a digital twin and its physical counterpart. In this context, all interviewees refer to real-time synchronization. Nevertheless, one interviewee (interview 4) preferred a semi-manual synchronization, allowing for a manual update of the digital twin and a fully automated solution. This is especially beneficial when dealing with use cases at an early stage of development, where the physical system is not yet equipped with devices for real-time communication, i.e., IoT-capable sensors.

The other two interviewees did not specify the level of automation of the synchronization. Nevertheless, both demanded a reliable synchronization, which draws a precise image of the real-time conditions:

"Now the components and requirements. […] It [the digital twin] should be easy to integrate and provide the transparency about the real real-time conditions."	Interview 1

This corresponds with many descriptions from the literature, e.g., [3], [4], or [11]. Hence, real-time capable synchronization is a critical requirement for digital twins.

4.2 Requirement 2: Data Sovereignty

Five out of six interviewees consider data sovereignty and control over data a mandatory requirement for digital twins. Data sovereignty is crucial for digital business processes as it enables active monitoring of data usage and the restriction of unwanted use [23].

Data sovereignty is essential for data sharing via digital twins:

"Interviewer: So, you are saying in this context there have to be certain requirements that you can restrict areas [of the digital twin], that you control access, or only release what you want to release and for how long you want to release it? Interviewee: Yes, absolutely, because otherwise, I possess a great model that I will never disclose to anyone because otherwise I am completely blank and lose my competitive advantage."	Interview 4

Interviewees agree that maintaining data sovereignty is fundamental for collaborative data sharing. However, as [24] state, digital twins form an essential basis for the collaborative use of technical data. Therefore, the consideration of data sovereignty is mandatory for digital twins. Based on the general importance of data security for industrial data sharing and the interviews, we see that the aspect of data sovereignty is of crucial significance for digital twins.

4.3 Requirement 3: Data Security, Data Protection, and Data Governance

Data governance and the related data security and protection mechanisms are the third requirement. Four interviewees agree with the importance of data governance for digital twins. However, the data governance may affect two aspects – the data and the digital twin:

"There is data governance via the data sources. Where does the digital twin get its data? Then it's the digital twin itself. That is more or less a data representation."	Interview 2

Data governance rules for data are not new, as they are generally necessary and determine any data handling processes. Nevertheless, data governance rules for a digital twin are a novelty. It is not surprising that these governance rules are requested, as a digital twin, as any digital object, permits data manipulation and, hence, needs rules for data protection and safety.

4.4 Requirement 4: Role allocation

Related to the data sovereignty and data governance, but introduced as an independent aspect, is the role allocation:

"A digital twin should be so modular that I have the option of making the digital twin or the functions of this twin accessible to certain user groups. So that it is a multiuser concept, with appropriate roles and permissions."	Interview 2

Half of the interviewees demand a role allocation. While this allocation is somewhat a standard procedure regarding data sharing and access tools, it is not typical concerning digital twins. The interesting aspect is that role allocation is demanded not only for the data inside the twin but also for the twin itself. Besides aspects like who may see data and contents of the digital twin, another essential aspect is the ownership and legal responsibility of the digital twin. This is particularly important for digital twins that accompany a specific product over its life cycle. The B2C sector, where the digital twin over all instances of the product line may stay with the manufacturer, does not seem to pose a considerable problem. Nevertheless, this circumstance may lead to significant disputes in the B2B sector. While company A sells the physical product to companies B and C, it wants to retain control of the digital twin. On the other hand, companies B and C are interested in possessing the digital twin data.

A rule catalog for these cases is mandatory. For example, the seller may offer instances of the digital twin, in which the buyer only accesses the data of his physical counterparts.

4.5 Requirements 5 & 6: Services of the Digital Twin

Recent works enhance the classical view of digital twins and demand that a digital twin provides certain services (e.g., see [25] or [26]). A service defines as a non-physical performance a company offers [27]. In this context, we define the services of a digital twin as possibilities to work with data within the twin.

Having a closer look at the literature about digital twins, simulation, prediction, monitoring, and analysis seem to be the most important services a digital twin offers [28,4]. The interviews back this expectation:

"I think one important point is a video analytics use case. For example, you could start using a "heat map" to make the topics and processes of employees transparent. You know that they are there today and are working well, and you have some characteristics or some functions that you can read from the scan points, but how do the processes run in detail, and what potential is there? These are the topics I would start with."	Interview 1
"The digital twin is also a model, a shortened representation of reality and, in this case, a simulation that automatically shows the current status."	Interview 4

The interviewees request these services as mandatory parts of a digital twin. Though, the interviewees distinguish between two specifications. On the one hand, the services monitoring and analysis represent one symbiosis, while on the other hand, the services simulation and prediction create the second aggregation. In both cases, a service that leverages the results of the preceding ones is merged. We follow the more realistic view and consolidate the different services into requirements five and six. A digital twin should contain monitoring and analysis as well as simulation and prediction services.

4.6 Requirement 7: Data Sharing and Interfaces

Besides the different services a digital twin provides, the interviewees requested data sharing capabilities and interfaces for data sharing.

"A shared digital twin is definitely a topic that is very, very interesting and very, very important for us that the digital twin runs across organizational boundaries. Because we are looking at the lifecycle here."	Interview 5

As described by the interviewees, a digital twin needs data from different entities when monitoring the life cycle. Therefore, a digital twin must have appropriate interfaces that enable such distributed data acquisition. Furthermore, these interfaces are even more critical if a digital twin has to represent logistics processes. In this case, multiple data sources from different entities of the supply network must be synthesized.

4.7 Requirement 8: Semi-Automation

Lastly, the level of automation must be analyzed. While interviewee 2 demands a fully automated digital twin, this is impossible for every individual use case.

„For me, it is already a prerequisite that this process is automated. That information flows automatically into these systems in which or from which the digital twin obtains its information or even directly flows into the digital twin automatically. “	Interview 2

Many use cases demand a manual interference opportunity. Infrastructural use cases even need manual interference interfaces for regulatory reasons. Therefore, in this context, it is necessary to have the option of manual intervention. This leads to the necessity of a semi-automated digital twin. The requirement is closely related to the first one. However, as requirement one concentrates on the (automated) synchronization, here a broader focus must be applied, as all processes within a digital twin are included.

4.8 Dependencies amongst the Requirements

A closer look at the contents of the requirements shows similarities between several requirements. Self-evident are the requirements RQM 2 – 4 and RQM 6 / 7. The first group of requirements is related to each other. All three requirements deal with rules and concepts for data security. Summarized, we subsume these requirements under the category of data policies. Similarly, requirements six and seven both describe the services of a digital twin. Hence, these requirements are subsumed under digital twin (DT) services. As stated above, these two requirements are functional requirements, which underline the service character of these two. The remaining three requirements, RQM 1, 5, and 8, describe how data is handled within a digital twin. Thus, we merge these three requirements in the category of data handling. These categories are preliminary and can be expanded or combined as further requirements arise since categorization is highly dependent on individual use cases.

	RQM1	RQM2	RQM3	RQM4	RQM5	RQM6	RQM7	RQM8
RQM1	0	0,6	0,75	0,66	0,5	0,66	0,6	0,66
RQM2	1	0	1	1	0,75	1	1	0,66
RQM3	1	0,8	0	0,66	0,5	1	0,8	0,66
RQM4	0,66	0,6	0,5	0	0,5	0,33	0,6	0,66
RQM5	0.66	0,6	0,5	0,66	0	0,66	0,6	0,66
RQM6	0,66	0,6	0,75	0,33	0,5	0	0,6	0,33
RQM7	1	1	1	1	0,75	1	0	0,66
RQM8	0,66	0,4	0,5	0,66	0,5	0,33	0,4	0

Figure 1: Correlations of the Requirements

Figure 1 shows further dependencies between the requirements. The figure is read in columns. We compare how often a specific requirement is mentioned together with another one. For example, each interviewee who demanded RQM 1 also mentioned RQM 2, whereas only two-thirds mentioned RQM 4. Fields with 100% show requirements that should be implemented together. Very high values scores RQM 1 – synchronization – and RQM 6 – simulation and prediction. Digital twins, which are synchronized, therefore need data sovereignty, data governance, and data sharing capabilities. This seems obvious, though, data sovereignty and governance are often neglected in practice. For reliable results, these policies are whatsoever mandatory.

Similarly, a digital twin that performs predictions and simulations requires reliable data inputs, as a solid database is essential for simulation purposes [29]. The comparatively low values for RQM 5, especially in conjunction with RQM 1, are surprising. Like the solid database for simulation, we consider a reliable and, above all, up-to-date database essential for monitoring purposes, but only half of the interviewees agree with this.

Another aspect is the distribution of the requirements in comparison to the sectors. Very important for logistics seems to be data sovereignty, the allocation of roles to users, and data sharing capability. This is plausible because of the nature of logistics as a highly distributed discipline, with many interfaces and different participants within one ecosystem. Hence, digital twins for logistics should focus on data sharing and distributing data while keeping measures in place to protect the data and underlying metadata.

	RQM1	RQM2	RQM3	RQM4	RQM5	RQM6	RQM7	RQM8
Logistics	66,67%	100,00%	66,67%	100,00%	66,67%	33,33%	100,00%	66,67%
Production	33,33%	66,67%	66,67%	0,00%	66,67%	66,67%	66,67%	33,33%

Figure 2: Sectoral Distribution of the Requirements

A peak of interest for one requirement is not evident for productional contexts. Interestingly, only the role allocation does not seem to play any role for manufacturers. We see this justified through the relatively small sample of manufacturers. Nevertheless, the domain logistics shows that a more significant research study with more interviews might bring more precise insights.

5. Conclusion, Limitations, and Contributions

In this contribution, we aimed to identify requirements for digital twins in logistics and production. For this purpose, we conducted an interview series with experts from the industry. Their answers were coded and analyzed. Furthermore, eight requirements were derived (RQ1). Namely, these are synchronization between digital and physical parts, data sovereignty, data security, data governance, and data policies, role allocations for a user with access to the digital twin, services a digital twin provides, e.g., monitoring and simulation, interfaces for data sharing, and semi-automated processes.

Related to RQ2, these eight requirements may be grouped into different categories, i.e., data handling, data policies, and digital twin services. These categories provide further opportunities to analyze more requirements depending on each category. Lastly, this research should show whether further research is worthwhile (RQ3). The relatively small interview series provides very interesting insights. Hence, a broader interview series will provide deeper insights and may bring specific requirements for certain domains.

Our paper is subject to limitations. While we focused on the highest level of objectivity, subjective influences cannot be ruled out during the coding process. Furthermore, the study is relatively small. But to find out whether this research approach is likely to be successful, we accepted the small sample. The scientific contributions show ways for further research. Broader studies focusing on particular domains or subjects of the digital twin should be carried out. Furthermore, this research provides progress to the body of knowledge of digital twins concerning needs the research on digital twins must tackle. As managerial contributions, eight distinctive requirements for practical digital twins are provided. Practitioners can include them in the respective developments of their digital twins. Additionally, knowledge about the requirements might help during the design phase of a digital twin, which most companies are now. As requirements lay the foundation for multiple scientific artifacts, and besides the already mentioned broader study on the requirements itself, numerous opportunities for further research are possible. For example, design principles, reference models, or concrete implementations of digital twins are thinkable.

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

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.

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Hendrik Haße (*1992) is researcher and did his PhD at the Fraunhofer Institute for Software and Systems Engineering. He holds a Master of Science in Industrial Engineering with a focus on Industrial Management from the TU Dortmund University. His research focus is on IoT architectures and the design of distributed Digital Twins. In cooperation with the Chair of Industrial Information Management at the TU Dortmund University he conducts his research on the conceptual structuring of Digital Twins.