Managing digital-twin lifecycle – recognition and handling of business risks

Rantala Tero, Saunila Minna, Ukko Juhani, Mikkola Aki, Kortelainen Juha, Zeb Akhtar

DOI: 10.4324/9781003054214-20

Managing Digital-twin lifecycle – Recognition and Handling of Business Risks

Tero Rantala (1), Minna Saunila (2), Juhani Ukko (2), Aki Mikkola (2)
Juha Kortelainen (3), Akhtar Zeb (3)
(1) LUT University, Lahti, Finland, (2) LUT University, Lappeenranta, Finland, (3) VTT Technical Research Centre of Finland

Abstract

While the adoption of digital twins among industrial companies is growing due to rapid developments in available solutions, the utilization of digital twins as a part of company operations and management is a new phenomenon. As a result, the long-term functionality of the digital-twin lifecycle is not well understood. Because of the small number of example cases, there is a lack of existing case data. This chapter offers both theoretical and empirical insights into the business-related risks that can arise during the different digital-twin lifecycle phases. The empirical information introduced here came from two Finnish multinational industrial companies that are planning to develop new service businesses based on digital twins.

Keywords: digital twin, lifecycle, risk, management

16.1 Introduction

The utilization of different types of digital twins among industrial organizations is becoming increasingly common as the possibilities and solutions developed by service providers continue to grow (Qi *et al.*, 2020; Tao *et al.*, 2019; Tao *et al.*, 2018). Currently, digital twins are increasingly being adopted and utilized by different types of manufacturing companies to support, for example, their daily engineering, production, management, and decision making. The digital twins provide these companies with a large amount of data from various processes. For that reason, company leaders from many different industries are becoming increasingly interested in supporting their operations management and business activities with effective utilization of lifecycle big data (Zhang *et al.*, 2017). From the business point of view, optimization of the process of digital-twin lifecycle management is an increasingly important objective for companies among different industries to improve their sustainable competitive advantage.

From the business point of view, the management and handling of risks arising during different digital-twin lifecycle phases generates new types of business-related managerial challenges. Because the use of digital twins as a part of company operations and management is relatively new and because of the small number of example cases, the long-term functionality of the digital-twin lifecycle is not well understood. More precisely, less attention has been paid to the recognition and understanding of managerial and business-related risks during different phases of the digital twin lifecycle. Because of a growing interest in the implementation and use of digital twins, the potential for business-related risk is growing, and there isn't much real information available to help mitigate this risk over the long term. Digital twins are being implemented as integral parts of overall systems, for example in power plants. Because their expected lifecycle might be decades instead of few years, business- and management-related risks related to this type of digital twin use cannot be ignored.

This chapter provides insights to help improve the understanding of risks related to the lifecycle management of digital twins from the business perspective. The aim of the chapter is to recognize risks related to different phases of the digital-twin lifecycle and provide information that will help businesses to prepare and deal with these risks. In addition to the recognition of the risks from the current literature related to digital twins, the chapter provides empirical insights from two large multinational Finnish industrial companies. These companies represent digital twin users that are planning to develop new service businesses based on their digital twin implementations. The company insights were gathered via semi-structured interviews with people representing different organizational backgrounds and levels.

The rest of the chapter is structured as follows. First, the theoretical background of the chapter is presented, including the definition of the digital twin as it is understood here. Next, the chapter gives a theoretical definition for the digital-twin lifecycle and describes associated risks and challenges related to the different phases of that lifecycle. The methodology for the empirical part of the study is then detailed followed by the presentation of results. The chapter ends with concluding remarks and discussion.

16.2 Theoretical background

16.2.1 Digital twins

The first mentions of the digital-twin concept are from 2011 (Tuegel *et al.* 2011). A hypothetical concept of a digital model of an aircraft was introduced that would be capable of representing its real-world counterpart in an ultrarealistic manner. This *digital twin* would include structural and aerodynamic details as well as operational loads and factors. Although a large amount of computational resources would be needed, the proposed digital model would be able to compute, in real time, the physical phenomena involved.

Since then, the concept of a digital twin has been under active research and development and has been defined in many ways. According to Grieves and Vickers (2017), the concept of having a representative digital model of a real physical system has a long history, and it has been referred to as a "conceptual ideal for PLM", a "mirrored spaces model", and an "information mirroring model". Grieves and Vickers (2017) define the concept as follows. "*The digital twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level*".

In their definition, the digital-twin concept is further defined as "a digital-twin prototype" and "a digital twin instance", the former being a digital representation of a prototypical physical artefact and the latter representing an individual instance of a product throughout its lifecycle. Similarly, Hartmann and Van Der Auweraer (2020) introduced the concept of "executable digital twin", which is based on existing simulation models developed during the product design and development phases. Such digital twins would be built according to specific applications and would have the required accuracy and performance. Together with their execution engines or simulation tools, these digital twins could be deployed on the edge (edge computing) or in the cloud. They could be used by autonomous machines or users with little experience. In both definitions of a digital twin, the authors are referring to physical products.

The definition of a digital twin can be extended from those referring to physical products or systems, such as aircrafts, to any kind of system such as industrial processes (Vachálek *et al.*, 2017) and even non-physical systems such as operational and organizational processes e. This wider interpretation of the digital-twin concept makes it difficult to categorize what a digital twin is or what it is not (Rasheed, San, and Kvamsdal, 2020). Nevertheless, the concept contains three main elements: the target system or product, its digital representation (the digital twin), and communication and data exchange between the target system or product and the digital representation.

The level of detail and the form of representation the digital twin has about the target system depends on the purpose of the digital twin. For example, if the purpose of the digital twin is to monitor and collect information about the state and condition of the machine system, it may represent a detailed structure of the target machine assembly that includes details of the individual components and their condition and history. On the other hand, if the purpose of a digital twin is to optimize the operation of the target system, *e.g.*, by minimizing structural loading and maximizing system performance, details of the dynamics of the target system are needed by the digital twin together with some optimization capabilities.

16.2.2 Digital twin lifecycle

The lifecycle of a digital twin refers to the existence of the digital twin itself, *i.e.*, its conception (beginning of life), its use, any possible modifications and upgrades (middle of life), and retirement (end of life). The evolvement of the concept of a digital twin builds on top of other concepts relating to digital models, such as “virtual prototypes” (Wang, 2003) (Madni *et al.*, 2019) and “cyber-physical systems” (Chen, 2017) (Nazarenko and Camarinha-Matos, 2020). In these concepts, the digital models of the physical systems contain features that are present in the design and engineering phase of the targets, *i.e.*, at the beginning of life of the physical system and the digital twin.

How the lifecycle of a digital twin refers to the lifecycle of the target system may differ. At the design and development phases of the product (beginning of life), the digital twin contains most of the information and possibly different models constructed to help design the product. Digital twin models are designed in virtual space according to the product operational needs and requirements. At this stage, the digital twin models may represent a generation of the product having similar characteristics.

These simulation models are used as digital-twin prototypes in the virtual space for experimentation and the analysis of product behaviors. Once the product is tested and the simulation results are considered satisfactory, the product is ready for production and instantiated from the digital twin models considering the unique requirements of the end-user. The product is then manufactured considering its potential use and operating conditions. At this stage, therefore, the digital twin models are modified and instantiated so that each digital twin corresponds to an instance of the physical product. Information from the digital twin can be directed back to the virtual space and used in the design of new generations of the product. This means that a digital twin can also be used for product lifecycles other than the one it explicitly represents (Tao *et al.*, 2019).

According to Haag and Anderl (2018), the current computer-aided design, manufacturing, and engineering models (CAD, CAM and CAE models, respectively, or CAx models) are not designed to be utilized beyond the product development phase, which hinders the automatic generation of digital twin models that can be used during the subsequent product operational phase. There is a need for development and maintenance of a “digital-twin template” in conjunction with the product at every phase of the product development process. Therefore, as the physical product is instantiated from the product models, the corresponding digital twin will be readily available from the digital twin template.

At the product operation and maintenance phase (middle of life), the digital twin evolves along the product lifecycle and captures all the information about its physical counterpart. The digital twin and the physical twin are linked through data that flows both ways, *i.e.*, from the physical product to the digital twin (*e.g.*, data about product performance, behavior, state, and configuration) and from the digital twin to the physical product (*e.g.*, predictions about product’s performance, failure, and life span).

A digital twin is a digital replica of a real product system. In the industrial or business context, this means that if the target system is a series product, there will be a series of digital twins, one for each product produced. In a successful business based on series products, the number of digital twins will increase over time, and the maintenance required for each will cover the lifecycles of all the products sold. In addition, when a digital twin is used in an industrial or business context, the resource aspects must be considered. As a result, the digital twin should be constructed automatically from the design and engineering data as a side product of the design work. During the operational phase of the product, the maintenance and possible modifications and upgrades of the digital twins should also be automated to cover the overall fleet of digital twins.

A digital twin should bring benefits to both the vendor and owner of the real asset. A digital twin will help the owner to monitor and optimize the performance of the physical product, and the vendor will be able to better design the next product generation using the information and knowledge gained from the digital twin. For a digital twin to accurately represent the actual state of its counterpart physical twin, timely modifications and upgrades must be carried out. The digital twin may come from the original vendor, or it may be provided as a service from a third party. In either case, strong collaboration among all the participants should continue to appropriately allocate responsibilities, ensure secure access, protect IPR, and receive fair rewards (Cameron *et al.*, 2018).

At the product disposal phase (end of life), the digital twin may be used for safe product disposal. Since the digital twin is a digital representation of the physical product, it contains information about, *e.g.*, product configuration and materials, which is useful for proper product disposal. Similarly, for a large and complex system, such as a process plant, a digital twin can help in demolition planning for the production process lines and structures by providing information about the available space around equipment and in the buildings and possible hazardous structures. The use of up-to-date digital models simplify planning and reduce the risk of accidents.

16.2.3 Lifecycle risks of digital twins

The digital twin contains all the information about the physical system, the data linking the real to the virtual, and the information linking the virtual to the real system throughout the digital-twin lifecycle (Schützer *et al.*, 2019). From the perspective of doing business with the digital twin, this reciprocal data flow introduces several potential risks along the entire lifecycle. These risks have been previously studied from the perspective of data lifecycle management.

The process of gathering, utilizing, and interpreting data introduces a number of risks. These include the loss of relevant data during data overloads (Tao *et al.*, 2019; Ofner *et al.*, 2013) as well as the possibility of duplicating data or receiving conflicting data from different sources (Tao *et al.*, 2019; Zhang *et al.*, 2017) and phases of the lifecycle (Tao *et al.*, 2018). There is also a risk of losing information across the boundaries of business units, departments, business processes, and systems (Ofner *et al.*, 2013). This information should be compressed as a small selection of useful information to support decision-making (Tao *et al.*, 2019).

Tao *et al.* (2019) have highlighted the necessity of combining data from different sources such as products, customers, and the operating environment. The unifying management and storage of the data (Zhang *et al.*, 2017) can decrease the risk of duplicating data from diversified sources. There is also a risk that the data collected in distinct phases of the lifecycle may become information islands that waste resources and result in data-sharing problems (Tao *et al.*, 2018). Furthermore, a lack of regulation or standards at the individual, organization, national, and international levels hinders the implementation of digital twins (Tao *et al.*, 2018).

Dealing with the *technology* leads to other risk types. If the technology cannot sense or completely capture the lifecycle data on time (Zhang *et al.*, 2017), it is a risk for the business. In situations where there is a need to respond rapidly to real-life events based on real-time data or to predict a future event based on historical data (Tao *et al.*, 2019), the lack of reliable technology is a risk. Also, ensuring efficient retention and destruction of collected data has been highlighted. According to Tao *et al.* (2019), improper data storage and transfer in a digital twin can result in severe mistakes. It is also crucial to assure validity and security in data transmission (Tao *et al.*, 2019). Finally, human-related risks deal with a lack of skills in mining and using the information coming from lifecycle data (Zhang *et al.*, 2017).

As presented above, there are variety of risks related to data lifecycle management. As the requirements for different phases of digital twin lifecycle differ (from early stages of systems development to detailed systems design, maintenance support, and process data feedback) (Garrido & Sáez, 2019), the same applies to risks. Therefore, being a novel and prominent form of technology, the risks related to different phases of the digital-twin lifecycle require further understanding.

16.3 Research methodology

The case study research methodology was used to collect the empirical data considered in this study. The case study method was chosen, because it is considered to be an appropriate research method to explore real-life cases under circumstances where researchers have the opportunity to observe and gather data in a realistic context (Yin, 2009; Voss *et al.*, 2002). The motivation for selecting the two case companies under investigation was to keep the number of cases low, which according to Voss *et al.* (2002) makes possible deeper observation.

The selected case companies are large multinational Finnish industrial companies that are planning to exploit possibilities provided by modern digital twinning to develop their service and product offerings. Since both companies are currently and actively exploring the potential of digital twins, these cases provide interesting and valuable real-life settings to observe possible risks related to different phases of the digital-twin lifecycle. **Error! Reference source not found.** summarizes the interview process that was used for data gathering.

Table 16.1. Process of empirical data gathering

Case company	Company type	Interviews
Company A	Large multinational machine and solution supplier in wood industry - Its customers are companies operating in the wood products industry	Group Vice President, Technology Business Line Manager Development Manager R&D Manager
Company B	Manufactures and services power sources and other equipment in the marine and energy markets - At the marine market customers comprise both shipyards and ship owners	Technology Manager Development Manager Product Development Manager

16.4 Results

The results of the interviews indicate that there are currently many open questions about the business risks associated with the lifecycle stages of digital twins and their identification. The results of the study also show that new business models based on digital twins, especially service-business-related business models, are a relatively new phenomenon whose potential is still being identified. Since there is a shortage of existing real-life cases, more evaluation of and more experience with longer-term business risks is needed.

In the first phase of the digital-twin lifecycle, one of the biggest business challenges relates to digital twin-related business logic and its design. When a new service business is designed based on the digital twin, there are costs associated with launching and developing it that should be recouped over the digital twin lifecycle. Based on the results from interviews, the business model related to digital twins that is currently more clearly conceivable and feasible seems to be based on a fixed monthly fee paid by the end customer, where the customer is willing to pay for the identified value-added features and elements. In this case, the business risk arising from the costs of setting up a digital twin remains with the product/plant supplier. During the lifecycle of the digital twin, the revenue stream becomes positive after the calculated time span.

Another, alternative model to deal with the digital twin's business risk is to outsource the operation of machines, production lines, or entire factories with profit responsibilities to their supplier. In such a digital-twin-related business model, the supplier operates the products it supplies using a digital twin, and the business benefit obtained is based on, for example, cost savings or improved efficiency. Such a business model is seen as a potential option in the near future, but at present there are still too many risk factors associated with uncertainties regarding digital twin accuracy and functionality, so business risk from operating products or facilities could be handled solely by suppliers.

In the "beginning of life" phase of the digital twin lifecycle; along with the delivery of new machines, production lines, or entire plants; end customers expect advanced and sophisticated visualizations of the products to be delivered. Providing these have gradually become common practice for sales and design operations. Digital visualizations are becoming increasingly sophisticated and complex with no additional cost being billed to customers. As a result, advanced visualizations to support sales and design work may also result in difficulties for the sale of digital twins at the "beginning of life" stage, because it may be difficult to identify additional features that a customer would be willing to pay for. Therefore, customers are accustomed to constantly receiving and utilizing more sophisticated digital visualizations without viewing the practice as a billable service.

In the “middle of life” phase of the digital twin lifecycle, from a business perspective, the main percentage of currently recognized risks seems to be related to the additional costs of the necessary changes, upgrades, and maintenance of digital twins over time. When designing the digital twin in the first phase of its lifecycle, it is assumed that the development and change of the operating environment will be anticipated and considered as accurately and comprehensively as possible. Nevertheless, changes due to the development of the operating environment pose business risks. For example, if the operational environment modeled by the digital twin changes faster or more than expected, the digital twins may need to face some major upgrades that may take too long to pay back.

Another risk associated with the change and development of the business environment in the second phase of the digital twin lifecycle is related to the development of the business model and earnings logic. As the business and operating environments of industrial companies continue to evolve, so do the digital twins, which are constantly and more cost-effectively offering new features and opportunities. This development will also allow business logic to be updated and diversified during the second phase of the lifecycle, but there is a risk that such features that will enable additional sales will not be identified or customers will be reluctant to pay more for them. Customers may assume that the features enabled by the development are part of the service to be provided in accordance with a previously agreed pricing principle.

From a business perspective, the second phase of the digital twin lifecycle also involves the most significant human-related risks and challenges. Based on the results, it is assumed that artificial intelligence and machine learning will soon become a growing part of the digital twin operating environment. In this case, digital twin implementation will partially or completely replace people in operational and business decision making. Thus, the digital twin will replace and displace existing skills and simultaneously demand that new skills be developed to replace them. Such machine learning and artificial intelligence expertise can be a significant business investment for companies with risks such as labor availability and price.

One of the major business risks during the second phase of the digital twin lifecycle is associated with the company replacing existing equipment with new and different equipment. digital twins may form factory-level entities in which all equipment and functions relevant to the operation of the factory are visualized under the same digital model. It is assumed that during the lifecycle of a digital twin, not all devices will come from the same equipment supplier. The introduction of a new supplier may lead to significant changes and additional costs for the operation of the digital twin. These may include, for example, the reluctance of the new entrant to share in the costs of maintaining the digital twin, an unwillingness to share information, or the inadvertent transfer of proprietary information to competitors.

Table 16.2. Business risks related to digital twin lifecycle

Phase of Lifecycle	Human related risks	Process related risks	Technology related risks
Beginning of life	Finding the necessary human-related skills in the beginning of life	Identification of the elements that the customer is willing to pay for is inadequate. Customer expects certain elements and visualizations with no extra charge. Business model and earning logic – who carries the risk of the payback and ROI?	Design of long term updating and maintenance of digital twin Digital twin is designed as a closed system.
Middle of life	AI and Machine learning are replacing humans. Finding the necessary human-related skills during the middle of life	Emergence of competitors on digital twin platforms Sales of additional services / additional features as functionalities evolve (customer may not be willing to pay for new services because they are thought to be part of the product features). Finding the balance between the incomes and costs of operating and updating of digital twins	The computing infrastructure (computer hardware, operating system, simulation software) may not be accessible or available for the long term, especially for digital twins with lifecycles in decades.
End of life		The digital twin does not return the investment during its lifecycle.	The end of lifecycle happens in an unpredicted and uncontrolled manner because of technology loss.

From a business perspective, the “end-of-life” phase of the digital twin currently appears to be the least considered and recognized. Digital twins are planned to last a long time. Little attention is currently being paid to the end of their lifecycle. End-of-life risks include a digital twin reaching the end of its lifecycle before it has paid for itself or a digital twin reaching the end of its lifecycle prematurely. The results of the interviews at different stages of the digital-twin lifecycle are summarized and presented in **Error! Reference source not found.**.

16.5 Concluding remarks

From a business perspective, in the first phase of the digital twin lifecycle, the most significant risks currently identified seem to be related to the business logic and balancing revenue streams and costs over the digital-twin lifecycle. Even though the identification of human- and process-related risks appears to be increasing in the second phase of the digital twin lifecycle, the technological perspective will nevertheless be emphasized in the consideration and identification of risks. To summarize the business risks associated with the digital twin lifecycle, the contemporary identification of risks emphasizes a technological perspective. First, the risk may realize, if the digital twin is designed as a closed system that can only be accessed by the service provider. Second, the risk may materialize, if the entire computing infrastructure (computer hardware, operating system, simulation software) is not be accessible or available for the long term. Third, the risk can realize, if the end of lifecycle happens in an unpredicted and uncontrolled manner. This can be, for example, a loss of technology if a service provider goes bankrupt.

While technology-related business risks are an integral part of the various stages of the digital-twin lifecycle, human-related risks also pose significant business risks for companies. For this reason, it would be important in future research to provide more information and an understanding of the human risks associated with the different stages of the lifecycle of digital twins and how companies could better prepare for them. As the results of this study also show that the identification of business risks related to the “end of life” stage of the digital-twin lifecycle is less compared to the beginning of the lifecycle, future research would also be essential to provide more information on and understanding to better prepare for the “end-of-life” phase risks.

Acknowledgements

The authors would like to thank all the stakeholders participating in the DIGIBUZZ (Toward Commercial Exploitation of the Digital Twins) project, as well as Business Finland – the Finnish innovation funding, trade, investment, and travel promotion organization – for the provided support to write this chapter.

References

Cameron, D. B., Waaler, A., & Komulainen, T. M. (2018). Oil and Gas digital twins after twenty years. How can they be made sustainable, maintainable and useful? 59th Conference on Simulation and Modelling (SIMS 59), 9–16.

Chen, H. (2017). Applications of Cyber-Physical System: A Literature Review. Journal of Industrial Integration and Management, 02(03), 1750012. https://doi.org/10.1142/s2424862217500129

Garrido, J., & Sáez, J. (2019). Integration of automatic generated simulation models, machine control projects and management tools to support whole lifecycle of industrial digital twins. IFAC-PapersOnLine, 52(13), 1814–1819.

Haag, S., & Anderl, R. (2018). Digital twin–Proof of concept. Manufacturing Letters, 15, 64–66.

Hartmann, D., & Van der Auweraer, H. (2020). Digital Twins. arXiv preprint arXiv:2001.09747.

Madni, A. M., Madni, C. C., & Lucero, S. D. (2019). Leveraging digital twin technology in model-based systems engineering. Systems, 7(1), 7.

Nazarenko, A. A., & Camarinha-Matos, L. M. (2020, July). The Role of Digital Twins in Collaborative Cyber-Physical Systems. In Doctoral Conference on Computing, Electrical and Industrial Systems (pp. 191–205). Springer, Cham.

Ofner, M. H., Straub, K., Otto, B., & Oesterle, H. (2013). Management of the master data lifecycle: a framework for analysis. Journal of Enterprise Information Management, 26(4), 472–491.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., Wang, L. & Nee, A. Y. C. (2020). Enabling technologies and tools for digital twin. Journal of Manufacturing Systems. (in press)

Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. IEEE Access, 8, 21980–22012.

Schützer, K., de Andrade Bertazzi, J., Sallati, C., Anderl, R., & Zancul, E. (2019). Contribution to the development of a Digital Twin based on product lifecycle to support the manufacturing process. Procedia CIRP, 84, 82-87.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology, 94(9-12), 3563-3576.

Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., ... & Nee, A. Y. C. (2019). Digital twin-driven product design framework. International Journal of Production Research, 57(12), 3935-3953.

Vachálek, J., Bartalský, L., Rovný, O., Šišmišová, D., Morháč, M., & Lokšík, M. (2017, June). The digital twin of an industrial production line within the industry 4.0 concept. In 2017 21st International Conference on Process Control (PC) (pp. 258–262). IEEE.

Voss, C.A., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. International Journal of Operations & Production Management, 22(2), 195–219.

Wang, G. G. (2003). Definition and Review of Virtual Prototyping. Journal of Computing and Information Science in Engineering, 2(3), 232–236. https://doi.org/10.1115/1.1526508

Zhang, Y., Ren, S., Liu, Y., Sakao, T., & Huisingh, D. (2017). A framework for Big Data driven product lifecycle management. Journal of Cleaner Production, 159, 229–240.