Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 83 (2019) 57–60

www.elsevier.com/locate/procedia

11th CIRP Conference on Industrial Product-Service Systems

Digital Twin in Services and Industrial Product Service Systems: Review and Analysis

Haiwen Zhang[a], Lin Ma[a,*], Jiao Sun[a], Hansheng Lin[a], Matthias Thürer[b]

[a]School of Management, Jinan University, Guangzhou, 510632, PR China
[b]School of Electrical and Information Engineering, Institute of Physical Internet, Jinan University, Zhuhai Campus, 519070, PR China

* Corresponding author. Tel.: +86-15102939217. *E-mail address:* malin15102939217@163.com

Abstract

Digital Twin is a term that was given to the concept of a virtual, digital equivalent of a physical product. However, most research to-date focusses on the monitoring of production equipment or large assets. This neglects the important role of services and Industrial Product Service Systems (IPS2) in value creation throughout a product life cycle. In response, this study used a systematic literature review to assess the current state-of-the-art of the literature on Digital Twin in the context of product service systems. An original sample of 59 papers was carefully analyzed, but only 2 studies appeared to focus on product service systems. Most of the remaining literature focusses on the use of Digital Twin for some forms of maintenance service. This study therefore calls for more research on the use of Digital Twin technology in the context of IPS2 and outlines possible applications for the stages in a closed loop product life cycle.

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Industrial Product-Service Systems

Keywords: Digital Twin; Services; Product-Service Systems; Systematic Literature Review.

1. Introduction

A “Digital Twin” is a term that was given to the concept of a virtual, digital equivalent of a physical product [1]. It was first coined in 2003 as part of an executive course on Product Lifecycle Management. Since then, it received broad attention in the literature. However, most of this attention focusses on the maintenance of the transforming resources that produce a product (e.g. [2, 3]), not on the product and its life cycle. It overlooks that a product life cycle consists of much more than the actual production process; in many industries does the profit margin for the provision of service parts and after-sales services far exceed the margin on the sale of the product itself [4]. Another important aspect of the product life cycle are therefore services associated with the product.

As a consequence, today the distinction between production of an actual physical product and services gets more and more blurred, and new business models as servitization (e.g. [5]) and Product Service Systems (PSS, e.g. [6]) emerge. Yet, little is known on the role of Digital Twin in these contexts. In response, this study uses a systematic review of the literature to explore the role of the Digital Twin in services and Industrial Product Service Systems (IPS2), this is “an integrated product and service offering that delivers values in industrial applications” [6].

The remainder of this paper is organized as follows. The method followed to conduct the systematic literature review is outlined next in Section 2. Section 3 then presents the results before a discussion that outlines possible applications throughout a closed loop product life cycle is presented in Section 4. Final conclusions are summarized in Section 5.

2. Method – Review of the Literature

This paper starts by asking: What is the current state-of-the-art of the literature on Digital Twin in the context of product service systems? To answer this question a systematic review

2212-8271 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Industrial Product-Service Systems.
10.1016/j.procir.2019.02.131

of the literature was conducted. A systematic procedure for retrieving and selecting the articles (following [7]) was used.

2.1. Sourcing of the Articles

The bibliographic database used for sourcing the articles was Scopus – due to its large coverage, e.g. compared to Web of Science, and its accuracy in terms of citation counts, e.g. compared to Google Scholar. In order to keep the number of articles reasonable and to ensure the quality of the sources, the search was restricted to peer-reviewed journal articles. Scopus was queried in December 2018 using the term: 'Digital Twin' AND 'Services'. To keep results to a manageable number, the search was restricted to the title, abstract, and keywords of papers. There was no restriction on the year of publication or the journals considered (beyond being peer-reviewed). For the search term, 83 articles were retrieved.

2.2. Screening of the Articles

The original sample of 83 articles was further reduced to 74 by excluding apparently unrelated articles (3) and articles not written in English (6). Using several channels for retrieving the full articles, a total of 54 articles were obtained. To ensure that we did not miss relevant articles, we further cross-checked the references in the 54 articles and, from this process, retrieved 5 additional relevant articles. This approach of supplementing the set of articles that had been mechanically retrieved helped to ensure that the list of articles was complete, but the number of articles added (5) was insufficient to suggest that the original search process was inadequate.

2.3. Analyzing the Articles

This stage involved extracting and documenting information from each of the 59 sources. To minimize subjectivity, the authors: (i) cross-checked results; and, (ii) conducted regular meetings to resolve any emerging inconsistencies in interpreting the results. Our major research vehicle was content analysis (see, e.g.[8]). As a template for data collection, a simple matrix was used where, for each paper (row), we asked (column) the following questions:

- What type of Digital Twin is used (Digital Model, Digital Shadow or Digital Twin?; see Table 1)
- How is the Digital Twin realized (for example, what core technology – Discrete Event Simulation, OPC-UA etc. – is used)?
- What is the Digital Twin used for (for example, product service system, service, what kind of service/product service system)?
- What were the results of the application of the Digital Twin?
- What research methodology was used (for example, conceptual, analytical or empirical)?

Before presenting the results of the analysis, Section 2.4 summarizes the basic sample characteristics.

Table 1. Differences in data integration across Digital Model, Digital Shadow and Digital Twin (based on [2])

	Data flow from physical object to digital object	Data flow from digital object to physical object
Digital Model	Manual	Manual
Digital Shadow	Automatic	Manual
Digital Twin	Automatic	Automatic

2.4. Sample Characteristics

Basic sample characteristics for the 59 articles are summarized in Table 2 and Fig. 1. Table 2 presents the distribution of journals across which the articles have been published. The sample contains articles from 33 different journals. This highlights the wide applications of Digital Twin technology across different fields. At the same time, most publications occur in journals specialized on manufacturing.

The distribution of articles by year of publication is shown in Fig. 1. A high increase in number of articles can be observed since 2016, indicating an increased interest of scholars in this topic. Interestingly, there were no publications from before 2016. On the contrary, several studies from before 2016 were identified in [2]'s review of Digital Twin in manufacturing. This means that the application of Digital Twin to services only recently received attention.

Other measures, such as the distribution of articles per country, author, etc. were obtained but did not provide any revealing insights and are therefore not presented here. Finally, note that only studies that are cited in this paper are listed in the reference list. A full list of articles can be obtained from the corresponding author upon request.

Table 2. The distribution of articles by journal

Journal title	n. of articles
IFAC-PapersOnLine	5
International Journal of Advanced Manufacturing Technology	5
IEEE Access	4
Journal of Ambient Intelligence and Humanized Computing	4
Procedia CIRP	4
Procedia Manufacturing	4
ABB Review	3
CIRP Annals	2
International Journal of Production Research	2
Journal of Manufacturing Systems	2
Robotics and Computer-Integrated Manufacturing	2
Others (include 22 different journals)	22
Total	59

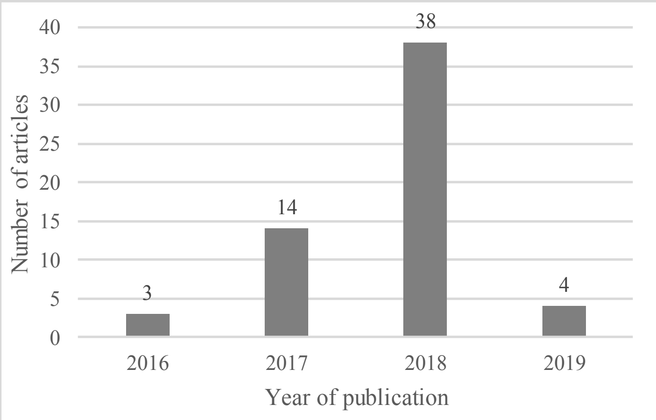

Fig. 1. The distribution of articles by year of publication

3. Results

Surprisingly, there are only two papers that are of relevance. First, [9] conceptually explores the potential of digital (or virtual) product twins in supporting after sales reconfiguration of products. Second, [10] discusses the use of Digital Twin technology to link the smart, connected product to the cyberspace. However, the actual application of producing customized facial masks in [10] then, arguably, works without Digital Twin: (i) the product is virtualized and product data sent to a 3D printer; and, (ii) users facial features are scanned and utilized for simulation of wearing conditions.

All other papers in our sample use the term “service” in a different context. For example, [11] discusses the transition from traditional support service to Digital Twin service for asset heavy Business-to-Business transactions. While this appears to focus on service it is more in the realm of cloud-based manufacturing equipment and its use to enable on-demand manufacturing services, as discussed in e.g. [12]. Meanwhile, [13] discusses Digital Twin service but only focus on the translation of the various components of Digital Twin into services with uniform description. In other words, the Digital Twin itself is provided as a service. In general, most papers discuss the “service” of health management and prognostics of physical assets, as discussed in e.g. [3, 14].

4. Discussion

[15] argues that Digital Twin technology enables smart production which allows for shifting the focus of adding value from production to other aspects of the product life cycle, such as product development. In other words, Digital Twin is not seen as supporting value creation in other aspects of the product life cycle than production. Our literature review seems to support this argument – the use of Digital Twin technology is confined to manufacturing. At the same time, the literature focusses on maintenance service of manufacturing equipment instead of products. This appears to run counter the original definition which sees a Digital Twin as virtual, digital equivalent of a physical product [1]. But, it can be explained by the nature of the product in the original applications, which requires a fixed position layout [16]. So, the question remains, is there a use for Digital Twin technology in other parts of the product life cycle than production?

A simple example that there is, is real-time tracking of product delivery as provided by most major e-commerce or food delivery companies. The map provides a digital model of the city which is updated in real time showing the location of the delivery. This form of logistic information supply is supported by the digital shadow as discussed in e.g. [17]. Another example is after sales product reconfiguration as discussed in [9]. In this example, however, Digital Twin technology is used to provide the service. In the previous example, Digital Twin technology is the service. So, there are two possible scenarios: Digital Twin technology supports the provision of the service and Digital Twin technology is the service used by the customer. This initial distinction is next used to identify applications for Digital Twin technology in a closed loop product life cycle [18].

4.1. Beginning of Life – Design and Manufacturing

Customization and personalization of products is seen as a major trend in manufacturing and product service systems [19, 20]. This requires that companies interact more closely with customers throughout the product life cycle, but specifically at the design stage when the product is developed. By employing the Digital Twin technology, the emergence of the design can directly be tracked by the customer. At the same time, the customer can implement and test modifications in the digital model and changes can directly be communicated to the company. Once the product is designed and enters production, the customer can track the progress of the production process (Digital Twin is the service). The digital model of the product and the shop floor allows for concurrent product and process design, significantly reducing cost and time from design to production. Once into production, the Digital Twin of the shop floor can be used to monitor production equipment during the production process to ensure quality (Digital Twin supports the provision of service).

4.2. Middle of Life – Customer Buys and Uses the Product

One of the significant benefits of Digital Twin technology is that it can provide real-time monitoring of the product state. An example is a fridge with a screen showing the content and additional information as the recommended date of use of a stable (Digital Twin is the service). At the same time, the information can be shared with a food delivery company that replenish stables in time and in accordance with the current allocation of food in the fridge (Digital Twin supports the provision of service). Note that the monitoring of stock levels to deliver just-in-time itself does not require a Digital Twin. Some simpler forms of electronic signal or even simpler devices as ‘shopping lists’ can be used. However, if the location of stock changes, physical space constraints also change. Considering the physical position of stock requires additional technology.

4.3. End of Life – Product Reuse, Product Remanufacture, Material Recycle and Material/Product Disposal

Products can be reused and shared in a community. A Digital Twin enables the shared monitoring of product usage as discussed in the context of production equipment in [12]. At the same time, customers can follow the recycling path of their product to ensure that the product is not only produced sustainably, but also recycled and disposed properly (Digital Twin is the service). Meanwhile, if there exists a Digital Twin for the product until this stage of the life cycle, then all information on the current state of the product is available. This provides the customer with the possibility to resell its product for product reuse or to buy a re-used or remanufactured product for which the life cycle is known. At the same time information can be used by the production company to recover parts or recycle material for reuse (Digital Twin supports the provision of service). A system along these lines was presented by [21]; however, in the proposed system information is manually updated in discrete time intervals.

5. Conclusion

Industrial Product Service Systems (IPS2) play a major role in value creation throughout a product life cycle. At the same time the concept of Digital Twin was introduced as part of a course on life cycle management and with specific focus on the product. However, while a broad literature on Digital Twin in the context of manufacturing emerged, little is known on the use of Digital Twin technology in the context of IPS2. In response this study asked: What is the current state-of-the-art of the literature on Digital Twin in the context of product service systems? Using a systematic literature, we found that only two studies discussed how Digital Twin technology can enhance service offerings. Most of the other studies identified in our systematic literature search focused on some forms of maintenance service for production equipment and large assets.

A major limitation of our study is its focus on Digital Twin. This neglects other forms of digital modelling, which may find wider applications in product service systems. At the same time, this restriction is intended since we want to identify applications for the Digital Twin or digital shadow, i.e. digital models where at least part of the information flow is automatic. Using the structure of a closed loop product life cycle we outlined possible usage scenarios. Future research is required to develop and implement the required technologies to apply Digital Twin in these scenarios. It is hoped that this unravels the full potential of Digital Twin in IPS2.

References

[1] Grieves M. Digital Twin: Manufacturing Excellence Through Virtual Factory Replication. [Online]. Available: http://www.apriso.com. 2014.

[2] Kritzinger W, Kamer M, Traar G, Henjes J, Sihn W. Digital Twin in manufacturing: A categorical literature review and classification, IFAC-PapersOnLine 2018;51, 11, 1016–1022.

[3] Tao F, Zhang M, Liu YS, Nee AYC. Digital twin driven prognostics and health management for complex equipment. CIRP Annals. 2018;67(1), 169–172.

[4] Cohen MA, Whang S. Competing in product and service: a product life-cycle model. Management Science 1997;43(4), 535–545.

[5] Cavalieri S, Pezzotta G, Shimomura Y. Editorial: product-service system engineering: from theory to industrial applications. Computers in Industry 2012;63(4), 275–277.

[6] Meier H, Roy R, Seliger G. Industrial product-service systems—IPS2. CIRP Annals-Manufacturing Technology 2010;59(2), 607–627.

[7] Tranfield D, Denyer D, Smart P. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 2003;14(3), 207–222.

[8] Krippendorff K. Content Analysis: An introduction to its methodology. 2nd Ed. Thousand Oaks, CA: Sage Publications; 2003.

[9] Abramovici M, Savarino P, Goebel JC, Adwernat S, Gebus P. Systematization of virtual product twin models in the context of smart product reconfiguration during the product use phase. Procedia CIRP 2018;69, 734-739.

[10] Zheng P, Lin, TJ, Chen CH, Xu X. A systematic design approach for service innovation of smart product-service systems. Journal of Cleaner Production 2018;201, 657–667.

[11] Bolton RN, McColl-Kennedy JR, Cheung L, Gallan A, Orsingher C, Witell L, Zaki M. Customer experience challenges: bringing together digital, physical and social realms. Journal of Service Management 2018;29(5), 776–808.

[12] Lu Y, Xu X. Resource virtualization: a core technology for developing cyber-physical production systems. Journal of Manufacturing Systems 2018;47, 128–140.

[13] Qi Q, Tao F. Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison. IEEE Access 2018;6, 3585–3593.

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

[15] Kuhlenkotter B, Wilkens U, Bender B, Abramovici M, Susse T, Gobel J, Herzog M, Hypki A, Lenkenhoff K. New Perspectives for Generating Smart PSS Solutions – Life Cycle, Methodologies and Transformation. In Procedia CIRP 2017;64, 217–222.

[16] Huang GQ, Zhang YF, Jiang PY. RFID-based wireless manufacturing for walking-worker assembly islands with fixed-position layouts. Robotics and Computer-Integrated Manufacturing 2007;23(4), 469–477.

[17] Bauernhansl T, Tzempetonidou M, Rossmeissl T, Erwin G, Jörg S. Requirements for designing a cyber-physical system for competence development. Procedia Manufacturing 2018;23, 201–206.

[18] Cao H, Folan P. Product life cycle: the evolution of a paradigm and literature review from 1950–2009. Production Planning & Control 2012;23(8), 641–662.

[19] Walzel H, Keddis N. Interconnecting Product and Process Information to Enable Personalized Production. Procedia CIRP 2016;52, 186–191.

[20] Ströer F, Sivasothy P, Faißt KG, Apostolov H, Thomas E, Bechev D, Bulun G, Seewig J, Eigner M, Sauer B. Combined development and test of product-service systems in early product development stages for customized, availability-oriented business models in the capital goods industry. Procedia CIRP 2018;72, 714–719.

[21] Wang XV, Wang LH. Digital twin-based WEEE recycling, recovery and remanufacturing in the background of Industry 4.0. International Journal of Production Research 2018; DOI: 10.1080/00207543.2018.1497819.