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Implementing Digital Twins to Enhance Digitally Extended Product-Service Systems

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Abstract

The role played by digital twins in the development of information-based services and digitally extended product-service systems can be based on realtime simulation and the Internet of Things (IoT), where the management system is Product Lifecycle Management (PLM). However, these areas are typically handled separately, because realtime simulation and PLM are owned by Research and Development, and IoT-based services are owned by Services. Companies collect sensor data from their installed base and use analytics to offer, *e.g.*, monitoring services. This collective insight, the digital twin, is typically not used to develop product-service solutions based on IoT-collected information and realtime simulation models. The study reported here was carried out to better understand the current situation for the case companies in these different areas and to collect evidence of existing digital-twin-based services that are information intensive. Learning how the subject companies use this insight to build better realtime simulation models that can be applied to services was a second area of interest. The work is based on semi-structured interviews with eight manufacturing companies to examine information-based services, simulation models, and IoT strategies.

Keywords: digital twin, services, product lifecycle, product-service systems, IoT, PLM

10.1 Introduction

The strategic driver for manufacturing companies of increased growth and improved margins is causing them to focus on developing new services. The traditional approach of offering services as a transactional add-on to products or providing spare parts has been replaced with a systematic approach. The servitization (Kotamäki *et al.*, 2018) of products is transitioning to a holistic Product-Service System (PSS) (Baines, *et al.*, 2007). PSS places demands on Business to Business (B2B) manufacturing companies, but also presents new business opportunities for them. The challenge they face can be divided into two areas: (1) engaging with the customer over the customer lifecycle and (2) moving from an asset-based view to better understanding the customers business and value proposition. Also, the business opportunities offered by this approach include (1) establishing deeper relationships over the customer lifecycle and (2) facilitating the outsourcing of business processes to a B2B manufacturing company. The introduction of information management technology has added another dimension to building extended digital service offerings that are based on data or knowledge about how the PSS is being used or should be used to establish a digitally extended PSS.

To move from an inside-out view of transactional product sales to providing continuous customer lifecycle service, a B2B manufacturing company must have periodic touchpoints along the lifecycle. These touchpoints can be realized by collecting lifecycle data for delivered products (assets) and then simulating the behaviors of these assets in a virtual environment (Grieves, 2019). Product Lifecycle Management (PLM) offers a way to ensure that the digitally extended PSS offered and the asset delivered can be managed systematically from the design phase all the way through the operations phase and to its end of life (Donoghue *et al.*, 2017). However, it is not clear how this can be accomplished via PLM. One approach that has been proposed is the implementation of a digital mirror of the real-world product (Grieves, 2006). The traditional goal of PLM has been to provide a management system that enables continuous product management over the product lifecycle with cross-functional responsibilities within the organization (Stark, 2006). However, this results in different parts of the organization taking responsibility for different phases of the lifecycle, which typically results in a situation where lifecycle phases are managed and executed separately. For example, Product Development owns realtime simulation information, PLM design data, and processes. Delivery owns marketing, sales, and supply chain data and processes, and Services owns assets, services, and service data and processed based of the Internet of Things (IoT).

In this chapter, digital twins are used to facilitate information-based services using information from the realtime simulation of the digitally extended PSS and data collected from assets in operation. To enable alignment between the digital twin and the assets, connectivity should exist between the two.

This can be accomplished if the Industrial IoT transfers data and information to provide insight into the current status of the PSS so it can be optimized to achieve the desired performance outcomes.

The study reported here was carried out to better understand the current situation for the case companies in these different areas and to collect evidence of existing digital-twin-based services that are information intensive. Learning how the subject companies use this insight to build better realtime simulation models that can be applied to services was a second area of interest. The work is based on semi-structured interviews with eight B2B manufacturing companies to examine information-based services, simulation models, and IoT strategies.

This chapter in structured and divided into the following sections. The first is the review of the related published research, followed by a discussion of the research methodology and approach for data collection, leading into the presentation of results for the research based on the interviews. Finally, general discussion and conclusions drawn are offered along with suggestions for further research directions.

10.2 Related Research

Baines *et al.* (2007) regard a PSS as a special case of servitization where the value of the product to the customer is increased with the addition of services. This establishes a concept of focusing on an outcome based on sale-of-use rather than sales of the product alone. Goedkoop *et al.* (1999) define the key elements of a PSS as (1) a tangible physical commodity manufactured to be sold, (2) an activity done for or on behalf of the customer that has an economic value based on a commercial contract, and (3) a system that is a collection of elements and the relationship formed between the product and associated services. Therefore, the customer pays for the sustainable use of the product, which is enabled through the integration of services across the lifecycle. This results in a PSS that is a system of tangible products and intangible services.

Mont (2001) extends the definition to include information or data-based services and connectivity through the addition of supporting networks and infrastructure. Mont (2001) also includes customer satisfaction and environmental impact reduction along the PSS lifecycle. Therefore, the focus of PSS is to support business models that provide periodic customer touchpoints following initial tangible product and delivery service sales. This results in a Long Tail Business Model (Gassmann *et al.*, 2014) where the focus is on B2B manufacturing companies that sell small numbers of systems, but have a large portfolio of products and services that makes a delivered solution (asset) possible and can offer the services needed to maintain the solution across its lifecycle. This also provides an opportunity, via continued engagement with the customer, to sell continuous services over the lifecycle of the PSS and offer sustained value to the customer.

Sääksvuori (2019) has shown that a PSS can be digitally extended to include digital services and data. It can be divided into different domains and several layers. He also suggests that digitalization changes the way product and services are designed, which results in more value for the manufacturer and customer (Sääksvuori 2015). Digitalization impacts the electromechanical composition of the PSS and how the PSS is manufactured. It enables new ways to optimize the supply chain and provides a periodic touchpoint over the customer lifecycle that fosters a continuous customer-provider relationship.

Grieves (2006) introduced the concept of the digital twin. The digital twin has been part of the PLM vision, and it is also seen as a key element to the development of new digital business models for business growth (Donoghue *et al.*, 2019). Grieves (2019) extended his previous concepts with the introduction of a dual Smart Connected Product System (SCPS) that can exist in the real world and the digital world at the same time. Grieves (2019) argues that the physical twin and the digital twin are connected continuously throughout the lifecycle with operational data being collected from the physical twin and sent to the digital twin to verify that the SCPS is operating within its performance parameters or identify when service activities should be done to sustain process performance as agreed upon with the customer. Alternatively, the digital twin can use multibody-physics-based real-time simulation (de Jalon *et al.*, 1994) to model the anticipated behavior of the physical twin in advance or to transmit to the digital twin information such as software upgrades, setup changes, or operational adjustments.

Grieves introduced three digital twin definitions that are related to the PLM lifecycle concepts introduced by Stark (2006), Donoghue *et al.* (2017), and Grieves (2006). These new digital-twin definitions are (1) the Digital Twin Prototype (DTP), used for the development of the product and all its variants, (2) the Digital Twin Instance (DTI), a digital copy of the instances delivered to the customer, and (3) the Digital Twin Aggregate (DTA), a collection of all the DTI used to aggregate information about the versions and variants delivered to gain insight about their operational and service correlations (Grieves, 2019).

The conclusions given by Donoghue *et al.* (2019) suggest that to successfully implement more digital-twin-based operations, a B2B manufacturing company must find a balanced way to collect data from the assets and learn more about how the digital twin is used to verify new services, and therefore minimize the risk of collecting so much data that it cannot be aggregated, assessed, and used by the business to create value.

The connectivity of SCPS (Grieves, 2019) or digitally extended PSS is critical to building value and developing new digital business models where the customer and B2B manufacturing company can cooperate through periodic touchpoints along the lifecycle (Donoghue *et al.* 2019). The result is a way of working in which time, location, or personnel do not hinder the cooperation. Verdugo *et al.* (2017) proved that PSS lifecycle value increases when the IoT is used to offer smart and digital services. The identified benefits were operational efficiency, risk minimization, sustainability, and value. To understand the role the IoT has in supporting PSS-driven business, Gubbi *et al.* (2013) defined the IoT and its role as follows.

the "Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications." (Gubbi *et al.* 2013).

Basirati *et al.* (2019) believe the IoT encourages the realization of new ideas, and that it can simplify PSS development and provide new digital-business models, closed-loop lifecycle management, and services provided via the IoT for PSS. These opportunities can also be extended to the SCPS (Grieves, 2019) for B2B manufacturing companies collecting sensor data from their installed base (asset) for use in analytics resulting in monitoring services, for example, and providing autonomy of the SCPS or PSS. McEwan *et al.* (2014) state that connectivity is based on the IoT and can be thought as being dependent on the following aspect.

IoT = PSS + integrated sensors, controllers, actuators + internet (+ digital twin).

McEwan *et al.* (2014) did not focus on what happens on the other side of the internet once the data was collected. In their model, they did not introduce the digital twin concept. This modified statement is based on Grieves (2019) concept for the SCPS to include digital twins. Grieves (2019) and Donoghue *et al.* (2019) both highlight that the IoT is essential for the connectivity and transmittal of bi-directional data. Vergugo (2017), Grieves (2019), and Donoghue *et al.* (2019) agree that the smart product, PSS, or SCPS also incorporate *smart* to the concept in both the physical twin and digital twin forming a foundation for an intelligent, connected digital twin. Smart products and smart digital systems are not new concepts, but connecting them upgrades an isolated smart system into an SCPS and a digitally extended PSS. The intelligence difference is similar to a factory robot that is managed by a central manufacturing execution system and internal local intelligence that can shut down the robot when it malfunctions versus an Unmanned Aerial Systems (UAS) that has edge machine learning and is connected to other UAS's and operational systems that use AI managed by a centralized intelligent digital twin (Grieves, 2019).

10.3 Research Methodology

Research data was collected between October 2017 and March 2018. From the data, eight companies were selected based on how well their situation aligned with the goals of the research. For these companies, qualitative research integrating theoretical and empirical case study data (Yin, 2013) was carried out through semi-structured interviews. Additional data from four other companies that had been collected from 2011 through 2019 was also included. For these four case companies, a *e* methodology (Hevner, 2007; Hevner *et al.*, 2004) was applied, and the data was also collected using semi-structured interviews. This approach was selected to better understand the start state of the case companies and gain insight into which were able to transition to information-based services, digitally extended PSS, or SCPS through the adoption of digital twins. The research process included two phases: (1) mapping the status of existing services and (2) examining changes over time as each company moved towards information-driven services or digitally extended products. The eight core case companies are all B2B manufacturing companies that deliver complex PSS having long operational lifecycles, which are either delivered configure-to-order or engineering-to-order.

10.4 Results

The results from the interviews were collected and organized into three categories that define the capability of the companies to create business value from digitally extended products, information-based services or Smart-Connected-Product-Systems (SCPS). The method to categorize company status is based on the Sääksvuori (2019) digitalization process, which is divided into three areas of interconnected domains that facilitate digitalization. Table 10.10.1 is divided into four columns. The first *Case Company* column lists the anonymous case companies. The second, *Business Process Digitalization*, shows the state of core business-process digitalization, information, and Information

System (IS) architecture. The third column is the *Connected Smart Product Systems*, where data collected from the physical and digital twins is used for simulation and performance verification. It is also used to send information back to the physical twin for performance adjustments and/or improvements. Finally, the fourth column lists *Digital Services*, which are divided into three Tiers. *Tier 1* is Remote/Monitoring Services, *Tier 2* is PSS optimization based on digital twins, and *Tier 3* shows services offered to customers who are not traditional clients (information as-a-services).

The goal of Table 10.10.1 is to quickly visualize the state of business capabilities to better understand how to leverage benefits from digitally extended products and gain insight into how far away they currently are from the SCPS (Grieves, 2019). The following criteria is used to map the current needs of the case companies. The capital letter (A – D) signifies digitalization characteristics. The number in the brackets (1 – 4) is used to define the numeric value that each company scores. D(1) indicates that data is not available to support the existence of this business capability. C(2) means the capability is partially needed in more than one but less than half of the business lines. B(3) indicates that the case company needs the capability for more than half of its business lines. A(4) denotes that more than 80% of its business lines still need the capability.

Case Company	Business Process Digitalization			Connected Smart PSS		Digital Services			Points
	Integrated Business Process	Digital Interfaces	Analytics for Steering	Data Collection	Digital Twin	Tier 1	Tier 2	Tier 3	Total
RO	B(3)	D(1)	D(1)	D(1)	B(3)	D(1)	B(3)	D(1)	14
SD	B(3)	C(2)	D(1)	D(1)	B(3)	D(1)	B(3)	D(1)	15
MN	D(1)	D(1)	D(1)	D(1)	B(3)	D(1)	B(3)	D(1)	12
VA	A(4)	D(1)	D(1)	B(3)	B(3)	C(2)	B(3)	D(1)	18
QE	A(4)	B(3)	B(3)	B(3)	C(2)	B(3)	C(2)	D(1)	21
VI	A(4)	A(4)	B(3)	B(3)	C(2)	B(3)	D(1)	D(1)	21
MT	B(3)	A(4)	B(3)	B(3)	C(2)	B(3)	D(1)	D(1)	20
VL	B(3)	A(4)	B(3)	A(4)	C(2)	B(3)	C(2)	D(1)	22
Max	A(4)	A(4)	A(4)	A(4)	A(4)	A(4)	A(4)	A(4)	32

Table 10.1. Digitalization Framework for Digitally Extended PSS and SCPS

The Table 10.1 results show that Integrated Business Process in the Business Process Digitalization column is an important need for all case companies scoring between B(3) and A(4). The Digital

Interfaces result falls into two groups. The first group includes those with the D(1) score, which means the questions or the interviews did not address this area. The second group companies need to build a foundation to establish integrated digital touchpoints. The Analytics for Steering column results are also divided into two groups. The first four case companies score D(1), and the second four score B(3) indicating a need to implement Analytics to Steering. Again, the D(1) score for the first group means the questions or the interviews did not reveal insight to support the need contain clear questions to uncover this need.

The results from Connected Smart PSS falls into the two sub-areas Data Collection and the Digital Twin. Once again, the results highlight that data collected from the various engagements differ, but they are not as polarized here. For the first four case companies, apart from case company 'VA', the Data Collection need is not evident. Data Collection focuses on using the IoT to collect data from the assets, and scoring D(1), data from selected companies RO – MN did not reveal this need. However, the B(3) indicates that data collection is a need for case company 'VA'. Nevertheless, the web pages for these companies claim that they offer these services to customers with data collected from the assets.

Cases Companies QE to VL scored between B(3) and A(4) also showing that Data Collection is a need, and they are already developing and offering this capability to customers. The sub-column Digital Twin result indicates that all the case companies have needs in this area with results ranging from C(2) to B(3). This results for this area is subject to how the case companies define a digital twin. The first four companies recognize the need and are implementing digital twins in the DTP form by applying real-time simulation and PLM.

The other companies operate with digital twins of various maturity levels that include PLM and simulation elements. They lack the connectivity between the digital twin and the physical twin that Greives (2009) defines for SCPS where information is transmitted to the physical twin or where data collected from the asset is used systematically in real-time simulations. And based on maturity level, the definition of the digital twin can vary among companies.

The last column Digital Services is divided into the three sub-headings Tier 1, Tier 2, and Tier 3. Tier 1 is Remote/Monitoring Services. The case companies from 'VA' to 'VL' show a need for these services C(2) – B(3), but 'RO' to 'MN' do not show this need. The company web pages of all the reviewed companies show they all offer these type services and there is ongoing work to develop these business capabilities as a customer offering. Tier 2 is PSS optimization with the use of digital twins. This is seen as a business opportunity for companies ‘RO’ through ‘QE’ and ‘VL’. However, this opportunity emerges through the discussion in the interviews and was not something that the case companies identified themselves upfront before the free discussions occurred. For companies ‘VI’ and ‘MT’, the research did not reveal evidence of a need. Finally, Tier 3 includes services offered to customers that are traditionally outside of the traditional customer base. The data from both research areas do not suggest recognition of this need. Based on the interviews and discussions with the different case companies, this does not seem to be area were any activity is ongoing.

The result D(1) indicates that the need cannot be identified from the existing data, however, it does not mean that the areas are not needed or that ongoing activities are not present at this time. The results for each case company from Table 10.1 can be averaged against the maximum points to reveal the relative situation for each company as shown in Table 10.2. The over-all average for the companies is 55.86% with the lowest average being 37.50% and the highest, 68.75%. This result could indicate that the questions and the collected data vary because of the engagement types. Data collection for the first four companies (‘RO’ to ‘VA’) was based on focused questions around realtime simulation, whereas, for the other group (‘QE’ to ‘VL’), data collection was based on Design Research, and the authors were actively involved in and gained better access to the internal goals for a longer period of time.

Case Company	Total Points	Average (%)
RO	14	43.75
SD	15	46.88
MN	12	37.50
VA	18	56.26
QE	21	65.63
VI	21	65.63
MT	20	62.50
VL	22	68.75
Average	32	55.86

Table 10.2. Case Company averages based on the adapted framework

10.5 Discussion and Conclusions

The main contributions of this chapter are addressing the shift beyond the multibody-physics-based real-time simulation to digital twinning. After establishing the presence of this shift, the chapter attempts to discover the link between product-service systems and the digital twins. This link exists in the PLM vision (Stark, 2015) (Grieves, 2006) (Donoghue *et al.*, 2017) and PSS research (Baines *et al.*, 2007). The objective to find a theoretical base for digitally extended PSS and SCPS exists based on the related research from Grieves (2019) and Donoghue *et al.* (2019) and Stark (2006) and the results of this paper.

The framework that was applied from Sääksvuori (2019) to test the shift towards a digitally extended PSS and then towards and Smart-Connected Product System (SCPS) cannot be proven without doubt based on the research data. It did not include or support the needs of all elements presented in the framework. However, there is strong indication that the case companies are moving towards a digitally extended PSS and/or SCPS. There is also evidence in Sääksvuori (2019) that one of the companies is clearly moving toward this strategy where the extended product can be divided into the hardware, software, product lifecycle services (PLS), asset efficiency services (AES), Digital Services, and Data.

The recommendations for business and entrepreneurs are to take a holistic view of how the different areas presented in this paper are related and how they must be approached through continuous development roadmaps implemented consistently to achieve a business model built on SCPS. Businesses must focus on getting their internal business processes digitalized before they can move to digitally extended products and SCPS. Academia has a role in researching this area further and discovering more established and verified concepts that businesses can apply in digitally extended PSS and SCPS. Clearly, most companies are developing the different aspects in silos, and a strategy and/or roadmap is often missing.

Finally, all the related research presented looks at the same phenomena from differing vantage points. e proposes a model that companies can use to understand the logical elements when integrated to form an intelligent Product Service System (iPSS) that combines the physical and digital twin with an IoT platform for connectivity and the integration of Machine Learning produce a digital twin capable of simulating the real world in real time or faster than real time to maintain solution performance and business sustainability (Figure 10.1).

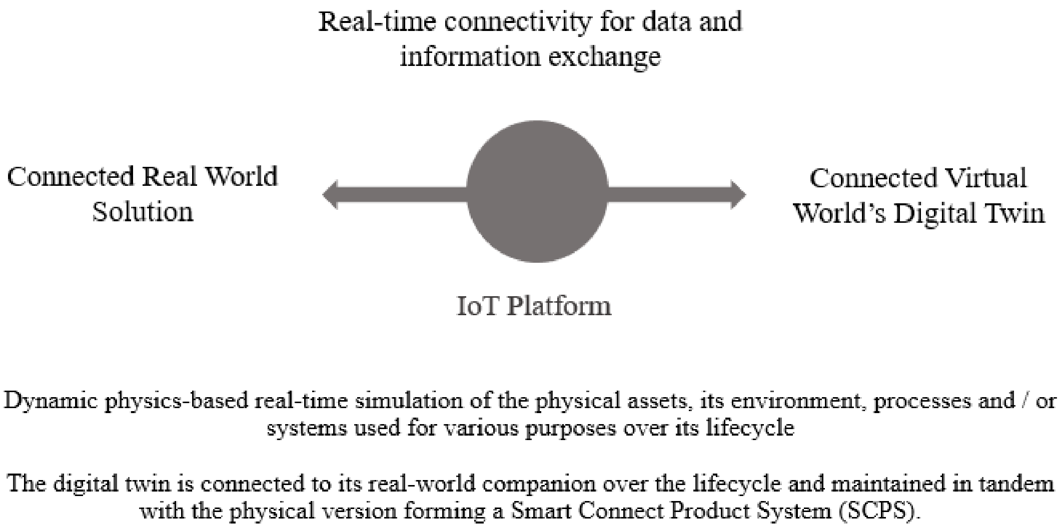

Figure 10.1. Intelligent PSS

The conclusions that can be drawn from this chapter are that the digital twin is an integral part of the future success of a B2B manufacturing company and that value can be achieved once the physical twin and the digital twin are connected and data/information can flow in realtime or close to realtime. Because this transformation depends on digital information and company data, success depends on integrating IS systems with the SCPS or iPSS. To achieve this, companies must develop new capabilities to change the nature of digitally extended PSS they offer. An obvious step for the digitally extended PSS is to include Artificial Intelligence (AI) either for human-to-system interaction or for Machine-to-Machine (M2M) operations. In these cases, the digital twin can be used to simulate reality faster than the real time giving insight into what could happen in time to take corrective actions before risks materialize.

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References

Baines, T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., ... & Alcock, J. R. (2007). State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: journal of engineering manufacture, 221(10), 1543-1552.

Basirati, M. R., Weking, J., Hermes, S., Böhm, M., & Krcmar, H. (2019). IoT as PSS Enabler: Exploring Opportunities for Conceptualization and Implementation. In Paper Presented at the Twenty-Third Pacific Asia Conference on Information Systems (PACIS 2019), Xi'An, China.

Donoghue, I., Hannola, L., & Mikkola, A. (2019). The value of digital Twins and IoT based services in creating lifecycle value in B2B manufacturing companies. Portland International Conference on Management of Engineering and Technology, 25-29 August 2019, Portland, USA. DOI: 10.23919/PICMET.2019.8893904.

Donoghue, I., Hannola, L., & Mikkola, A. (2018). The Benefits and Impact of Digital Twins in Product Development Phase of PLM. In: Product Lifecycle Management to Support Industry 4.0., Eds. Chibert, P. *et al.*, pp. 432-441.

Donoghue, I., Hannola, L., & Papinniemi, J. (2017). Product Lifecycle Management Framework for business transformation. 24th International Conference on Production Research, July 30 - August 3, 2017, Poznan, Poland.

Gassmann, O., Frakenberger, K., & Csik, M. (2014). The Business Model Navigator. Pearson Eductation Limited, ISBN 978-1-292-06581-6.

Goedkoop, M., Van Halen, C., te Riele, H., & Rommens, P. (1999). Product Service-Systems, ecological and economic basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ).

Grieves, M. (2006). Product Lifecycle Management. Driving the Next Generation of Lean Thinking. McGraw-Hill, USA.

Grieves M., & Vickers J. (2017) Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In: Kahlen FJ., Flumerfelt S., Alves A. (eds) Transdisciplinary Perspectives on Complex Systems, pp. 85-113. Springer, Cham.

Grieves, M. W. (2019). Virtually Intelligent Product Systems: Digital and physical twins. Complex Systems Engineering: Theory and Practice, 175-200.

Grieves, M. (2006). Product Lifecycle Management. Driving the Next Generation of Lean Thinking. McGraw-Hill, USA.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future generation computer systems, 29(7), 1645-1660.

De Jalon, J. G., & Bayo, E. (2012). Kinematic and dynamic simulation of multibody systems: the real-time challenge. Springer Science & Business Media.

Hevner, A. R. (2007). A three cycle view of design science research. Scandinavian journal of information systems, 19(2), 4.

Hevner, A., & Chatterjee, S. (2010). Design science research in information systems. In Design research in information systems (pp. 9-22). Springer, Boston, MA.

Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology. DOI: https://doi.org/10.1016/j.cirpj.2020.02.002.

Kohtamäki, M., Baines, T., Rabetino, R., & Bigdeli, A. Z. (2018). Practices and Tools for Servitization. Springer.

McEwen, A., & Cassimally, H. (2013). Designing the internet of things. John Wiley & Sons.

Mont, O., (2000). Product Service-Systems. The International Institute of Industrial Environmental Economics (IIIEE), Lund University, Stockholm, ISSN 1102-6944.

Singer, P. W., (2009). Wired for war: The robotics revolution and conflict in the 21st century. Penguin.

Sääksvuori, A., (2019). Digital and Modular Services as Part of the Offering in Manufacturing Industry. Krios Business Consulting Oy, Espoo 2019.

Sääksvuori, A., (2015). Extending Products Digitally. Sirrus Publishing, ISBN 978-952-67529-4.

Stark, J. (2006). Product Lifecycle Management – 21st Century Paradigm for Product Realisation. Springer-Verlag London Limited, ISBN 1-85233-810-5.

Verdugo Cedeno, J., Papinniemi, J., Hannola, L., & Donoghue, I. (2017). Developing Smart Services by Internet of Things in Manufacturing Business. 24th International Conference on Production Research (ICPR 2017).

Yin, R., K. (2013). Case Study Research: Design and Methods. SAGE Publications, 312 p.