Digital Twin based Decision Support Services in Business Operations

Jürg Meierhofer[1], Lukas Schweiger[1], Lukas Schreuder[2]

[1] School of Engineering, ZHAW Zurich University of Applied Sciences, Switzerland
juerg.meierhofer@zhaw.ch, lukas.schweiger@zhaw.ch
[2] Shiptec AG, Lucerne, Switzerland
l.schreuder@shiptec.ch

Abstract. With the advent of servitization and against the background of progressive digitalization, industrial value creation is increasingly shifting to service interactions at the customer interface. Companies are focusing less on selling goods and more on creating service values. The goods remain important as carriers of service values. The concepts of the Service-Dominant Logic (S-D Logic) prepare this shift in conceptual and theoretical foundations by providing a new perspective that puts the co-creation of values in service ecosystems at the core of the conceptual design. Service delivery is significantly supported by the increasing capabilities of digital and data-driven tools (Lusch & Nambisan, 2015).

In business-to-business (B2B) environments, the benefits of services manifest themselves primarily in business-relevant decision making. By using data, the consequences of decisions can be better predicted, reducing uncertainty for management and increasing the quality of decisions.

This paper examines the modeling of decision support by digital twins in business processes with a consistent focus on service value creation for the human actors in the system. For this purpose, decision making is modelled as a multi-stage process that can be represented by different elements of digital twins. The conceptual study is accompanied by an implementation in a real company case study. This case shows how the elements of digital twins interact to create service value and what kind of data is required to create this value.

Keywords: Smart Services, Digital Twin, Decision Support.

1 Introduction

In business-to-business (B2B) environments, services are applied to provide value to both external partners (i.e., customers) or internal users (i.e., employees) of a company. In these types of situations, the benefit of services is manifested primarily in the support of business-relevant decisions. Business decisions are very frequent in operational processes and are accompanied by the inherent uncertainty about their consequences.

This poses major challenges for operational management and is a major pain, which represents significant potential for the application of systematically designed data-driven service ecosystems. Data-driven management means taking such decisions supported by data - for example, process data, data created by customer assets, or data from other actors in the ecosystem: by using data, consequences can be better predicted, which reduces management uncertainty and increases the quality of decisions. The Digital Twin as an adequate data-based representation of real objects represents a concept that has the potential to provide value for data-driven decision support.

The research underlying this paper aims at understanding, modeling and optimizing how value is created by Digital Twin-based decision support services in operational processes, in particular – but not exclusively – in manufacturing companies. For this goal, the process of decision taking and its support is described through the lens of service science and Service-Dominant Logic, thus enabling a business value-oriented perspective – characterizing decision taking processes in operational environments and modeling their impact on value creation on a combined quantitative and qualitative basis.

2 The Evolution of Servitization of Manufacturing towards Data-driven Industrial Services based on the Digital Twin

The concept of servitization of manufacturing moves industrial value creation from the goods perspective to the service perspective, where value is created in the interaction between providers and beneficiaries (Kowalkowski & Ulaga, 2017; Lightfoot et al., 2013; Vargo & Lusch, 2008). In this transition from goods to services, the concept of so-called product services systems (PSS) has emerged (Oliva & Kallenberg, 2003; Tukker & Tischner, 2006) where products deploy their value via services.

With the emergence of digitalization and the internet of things (IoT), service value creation by data-driven services is a topic of increasing importance in industrial environments, leading to the concept of the industrial internet of things (IIoT) or Industry 4.0 (Thoben et al., 2017; Weimer et al., 2016). Data-driven services enable so-called advanced services, which are output-oriented services, where the customer gets a promised level of output for an agreed price. Data science (also referred to as advanced analytics, machine learning, artificial intelligence etc.) represents an enabling factor for providing advanced services (Paschou et al., 2020).

The Digital Twin is defined as a virtual representation of a connected physical equipment that represents in real-time its static and dynamic characteristics (Romero et al., 2020). It has the potential to add value to many applications and, in particular, to industrial processes and thus attracts increasing interest of practitioners and scholars (Barbieri et al., 2019). There is a wide range of understandings and definitions of the Digital Twin and its applications (Tao et al., 2018). In the literature, the Digital Twin is mainly discussed as a technical tool that has diverse interpretations (Meierhofer & West, 2019) which vary widely depending on the industry and implementation field (Tao et al., 2018).

The research streams of industrial services, data-driven services and Digital Twins converge in the field of decision support services. The Digital Twin can be considered as an implementation of data-driven services that enable the exploration of scenarios and alternatives and thus support decision taking in business environments (Kunath & Winkler, 2018). Therefore, changing the perspective and conceptualizing the Digital Twin as an approach for value creation from a service perspective is a promising new research direction (Barbieri et al., 2019).

3 Decision through the Lens of Service-Dominant Logic

According to Service-Dominant Logic (S-D Logic), considering service as the fundamental purpose of economic exchange, value is created by actors integrating resources to create new so-called operant resources which create benefit for other actors (Vargo & Lusch, 2008). The support for decision taking can be considered from this perspective as a way of creating benefit for the decision taker. The resources integrated are: a) the expert knowledge of the human actors in the system, b) the data created by the actors, in particular by the equipment, people and processes that are to be managed, c) the analytics applied to this data, d) the decision taking process based on the integration all these resources.

This process of integrating knowledge and data from their raw formats up to supporting decisions is based on (Holsapple, 2008). The structure is comparable to the DIKW (data-information-knowledge-wisdom) scheme based on (Rowley, 2007). According to (Holsapple, 2008), the traditional conception of decision taking has to be differentiated from the knowledge-based conception, which – according to S-D Logic terms – integrates knowledge resources other than pure data from the systems.

4 Industrial Decision Support Systems Supported by Digital Twins

Decision Support Systems (DSS) are information systems that help users in their decision activities, which can extend to highly automated decision taking. The steps of the decision taking process are described in (De Almeida & Bohoris, 1995; Dong & Srinivasan, 2013; Holsapple, 2008; Power, 2004, 2008; Sala et al., 2019) and can be simplified to: 1. Describe the set of possible actions or alternatives. 2. Evaluate these actions. 3. Select the preferred action. This can be followed by additional steps for recording and analyzing the decision and using it for improving future decisions.

Step 2. of the simplified decision process points to the application of the Digital Twin, in particular Digital Twin-based simulation, which allows to explore the variants and evaluate their consequences. This is supported by (Sala et al., 2019), which states that simulation is a very common decision support instrument, in particular for decisions in maintenance and capacity planning in product-service-systems. Several industrial application cases of Digital Twins are described in the literature. (Kunath & Winkler, 2018) elaborate how a Digital Twin of the physical manufacturing model is applied to scheduling, the calculation of delivery dates and dynamic pricing as well as the dynamic administration of supply processes. In (Zhou et al., 2016) the application of agent based simulation for service technicians is described for conducting experiments with variations of the number of technicians or the service policy – e.g., the number of maintenance periods after which the equipment is replaced. (Huynh et al., 2010) discusses the application of Digital Twins of machines or equipment for decision support and (Xia et al., 2009) takes into account a Digital Twin of processes.

Operational decisions are taken in the interplay between the product (the equipment) and the operational processes. The Digital Twin of the equipment gets data (e.g., a health condition or a performance indicator) from the physical equipment, i.e., a machine. However, this is considered raw information for better understanding, but does not support the actor taking decisions. Based on the information from the Digital Twin of the equipment, the additional step with the Digital Twin of processes can support decision taking along the lifecycle as shown in Table 1 (Meierhofer et al., 2020; Meierhofer & West, 2020):

Table 1. Support services provided by the process twin across the lifecycle.

Beginning of Life (BOL)	Middle of Life (MOL	End of Life (EOL)
- Process design decisions - Capacity design decisions - Automation (vs. manual) design decisions	- Capacity vs. demand decisions - Quality decisions - Maintenance decisions - Skills development decisions	- Process redesign decisions - Re-skilling workforce decisions - Process design for recycling or refurbishment

In the MOL phase, for example, an actor managing an asset takes decision by trading off resource constraints, e.g., between maintenance – requiring available maintenance resources, or replacement – requiring available spare equipment, or any point on the continuum between these two extremes.

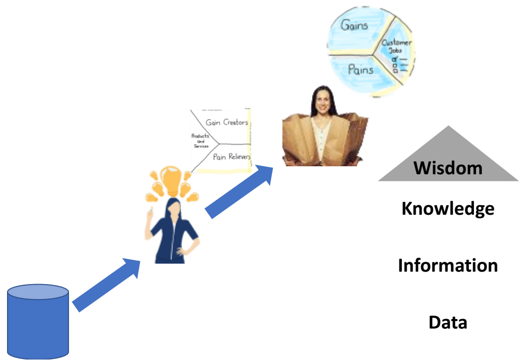

Fig. 1. Enriching raw data to information and knowledge and integrating it with human knowledge to support decision making.

In the industrial sector, this typically boils down to the concept of data-driven management in operational processes. Data-driven decision support is an essential part of this. Here, operational decisions are made on the basis of data: by using data (for example, internal process data or customer data), consequences can be better predicted, which reduces a management pain and increases the quality of decisions. This process, which turns raw data into good decisions, can be visualized by the so-called DIKW pyramid (Fig. 1): information is created from digital raw data by interpreting it in context. Knowledge, however, is only created through analysis. Combined with management knowledge, this results in the balanced assessment ("wisdom") required for the decision, on the basis of which digital (data-driven) products develop their business benefits in interaction with the users.

5 Case Study: Application for Decision Support in Ship Operations Processes

5.1 Introduction to the Shipyard Case

Shiptec is a swiss shipyard located in Lucerne which designs, develops and builds inland water vessels for professional applications. These include ships as public transport, tourist activities, ships for the transport of goods as well as government and rescue boats. Shiptec offers all related services, from strategic maintenance planning to short-term technical operations. Shiptec has extensive experience in the holistic analysis and design of energy and drive systems and is a leading engineering company to reduce the ecological footprint of fleets or to gradually achieve zero emissions. Shiptec is an associated company of the navigation company of Lake Lucerne (SGV Holding AG). The SVG Holding consists of the three members Tavolago AG (gastronomy), SGV AG (navigation company) and Shiptec AG mentioned above.

Passenger transportation on inland lakes and rivers was once the fastest means of transport before it was replaced by the cars, busses and trains. With today's need for mobility, the capacities of these transport routes reach their limits. Particularly in metropolitan areas and on main connecting routes, the roads are congested and the capacity limits of the trains are exhausted. The waterway becomes again more important as an addition to existing commuter routes. Because a vessel is a long-term investment of 30+ years, technical evolutions did not happen in the same pace as for private and public transport vehicles, which have evolved heavily over the last decades in terms of ecology, economy and comfort. With the arrival of new and cleaner hybrid and purely electric propulsion systems for inland vessels, it brought many sensors onto the water and made the vessels more digital. This makes it possible to monitor vital ship data in real-time to improve the ship availability, power and fuel consumption and passenger comfort.

The combination of the increasing demand for more and greener mobility on one hand and the availability of modern technology on the other hand creates new business cases previously not deemed profitable for a navigation company and opens new markets for a traditional shipyard. In particular, this situation lends itself to a systematic servitization approach as described in the introduction of this paper. For these reasons, Shiptec joined a research project on smart services based on Digital Twins with the aim of developing a Digital Twin which would support decision making in the existing ecosystem of Shiptec and its partners co-created the case following hereinafter.

5.2 Ecosystem Mapping

The business system of the vessel transportation is analysed applying the service-oriented concepts provided by the framework of the S-D Logic. To better understand the complex business landscape around Shiptec, according to (Meierhofer et al., 2020) an ecosystem analysis was done. The ecosystem map in Figure 2 Ecosystem Map Shiptecshows the main actors and their connections. In the case of Shiptec, multiple actors were identified. The inner core of this ecosystem and its actors is depicted in Figure 2.

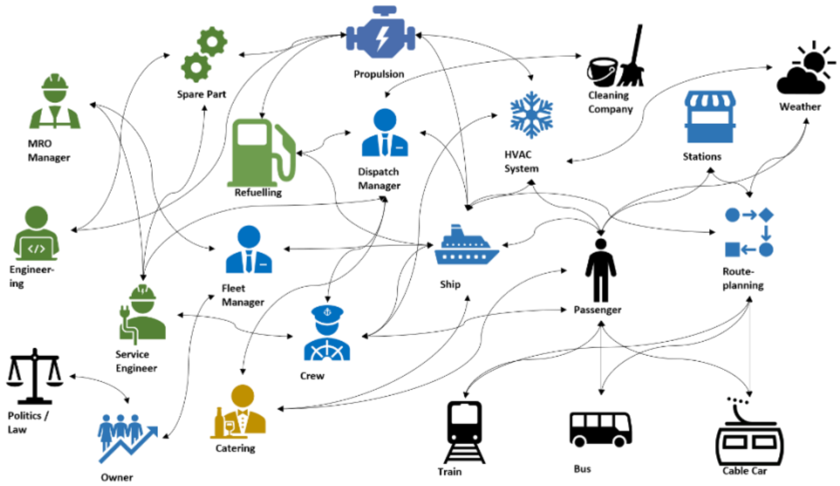

Figure 2 Ecosystem Map Shiptec

During the mapping of the ecosystem, different interactions between actors have been investigated. The actors which are colored in green are members of Shiptec. The blue ones are members of the SGV and the golden one from Tavolago. The black ones are external actors that influence the ecosystem. Out of this service ecosystem, several actors were selected to build new services around Digital Twins for them. For framing the procedure according to the concepts of the S-D Logic, practical methodologies of service design approaches were applied. According to (Vargo et al., 2018), service design (Stickdorn et al., 2018) can be considered an operationalization of SDL. In particular, the value proposition design tools (Osterwalder et al., 2014) provide a suitable means to research user insights about the beneficiaries by investigating their jobs, pains, and gains.

The primary beneficiaries are listed below with their job's, pains, and gains. During the iterative model development, the range of potential beneficiaries was continuously extending. Therefore, there are multiple beneficiaries and not just the one with which the case was started.

5.3 Primary Beneficiaries

Along the iterative process of modeling, the four actors described below tunred out to be the most relevant beneficiaries of Digital Twin based services.

Dispatch Manager (SGV)

The job of the dispatch manager is to make sure that the right amount of crew is at the right time on the right ship. In addition, he has to create the timetables for the ships and organizes the refueling and cleaning of the ship. His greatest pains are: unplanned breakdowns of ships, high level of fuel usage, paper-intensive communication processes, interfaces between different planning tools, and the integration of theme tours into the regular schedule. The gains of the dispatch manager are: a stable, planned schedule, appropriate capacity (size of ship) timely available given the demand (number of waiting passengers), thus resulting in reduced waiting times.

MRO Manager (Shiptec)

The job of the MRO manager is to plan and organize the maintenance and repair, planned and unplanned, for the customers of Shiptec. His main pains are: missing spare parts and the long waiting time to get these, due to misleading information and missing data from the ships, as well as sending the wrong technician. Also missing appreciation internally as well as from external customers as well as when customers do not have a centralized channel to report failures and problems. His gain is the low failure rate and high availability of the ships. Knowing the ship’s health status at any time and knowing in advance when parts are going to break.

Service Engineer (Shiptec)

The job of the service engineer is to repair and maintain the ships at the customer's site. This includes going on board looking for the error and fixing it with little to no information where the error may be located. Prioritize the different error messages and act accordingly. Get in contact with the ship crew to decide if the ship can still be used or needs to be replaced. His greatest pains are: frequently not having the right tools to fix the ships because it was not clear where the problem occurred, too little time to fix the problem on the ship, need to visit the ship several times per error message due to the lack of information.

Owner (SGV)

The job of the owner is to operate a fleet of ships in the most profitable and sustainable manner. His main pains are: ships not operating at full capacity, high fuel consumption, unplanned maintenance events. His gains are reliable planning of recourses and investments, reduction of operation costs such as fuel, spare parts, maintenance, and labor cost.

5.4 Model

The model is built to support these primary actors in the ecosystem of Shiptec to support decision making. As a modeling tool, AnyLogic was used, which enables building agent-based, discrete event, and system-dynamic models in the same environment (Figure 3). The model was co-created with Shiptec in an iterative process. This was done to focus on the jobs, pains, and gains of the primary actors in the ecosystem of Shiptec. The aim of the model is to support the different actors in the ecosystem with possible options of reactions in situations where complex decisions need to be taken.

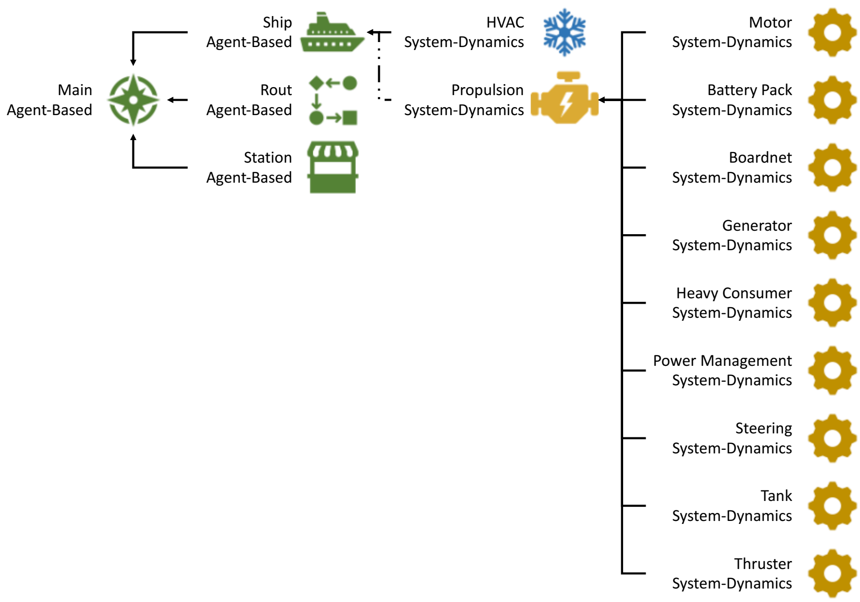

Figure 3 Structure of Final Model

5.5 First Iteration – Operations Model

In the first iteration, an agent-based operations model was built, i.e., a digital twin of processes according to section 4. The model consists of four agents: Main, Ship, Station, and Route. The "Main" agent is the route environment where all the other agents are placed in and interact with each other. The primary beneficiaries of this model are the Dispatch Manager, the MRO Manager, and the Service Engineer. With the model, different operations states and their implications on the current situation can be simulated. This helps the dispatch manager to take capacity decisions during the operation of the ships on the Lake of Lucerne. For example, the dispatch manager and the MRO manager are able to use the model to calculate the optimal replacement constellation in the event of ship failure. This calculation takes the different routes and ships that are in use on the Lake into consideration. Such calculations can be done in near-real-time or at the end of a day for the upcoming days if a ship needs to go into maintenance. The resulting simulation model is shown in Figure 4.

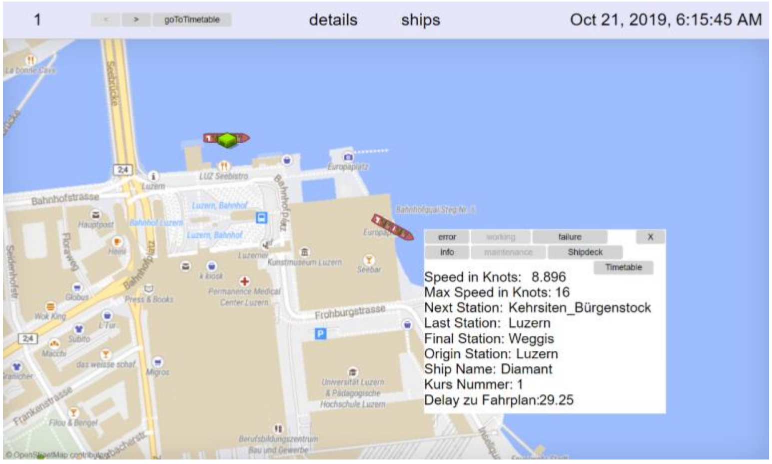

Figure 4 Print Screen from Simulation of the Operations Model

5.6 Second Iteration – Integration of HVAC

During the first iteration of building the model, it became evident that by adding a simulation of the Heating, Ventilation, and Air Conditioning (HVAC) of the ship the simulation could also support the crew by providing them with information about the development of the indoor climate on the ship. Therefore, the HVAC system of one ship was added to test the approach and to test if it creates value. This represents a digital twin of an equipment according to section 4.. This was done using a system dynamics approach. This addition to the model should benefit the crew as it would be able to simulate the influence of the HVAC system onto the climate on board. Often, they have to decide if it is economical to use the HVAC system between two stations. With this addition to the digital twin, this pain could be resolved, and indirectly relieves pains of the primary beneficiary "owner".

5.7 Third Iteration – Propulsion Model

Based on the learnings from the previous two iteration steps and considering the needs of service engineer (and additionally the crew and the engineering department) to better understand the behavior of the ship's behaviour, a further addition to the digital twin was made, which is able to simulate the propulsion system of one of the ships of the

SGV, which is an additional digital twin of an equipment according to section 4.. It is a pure system dynamics model that should help, on the one hand, the engineering department and, on the other hand, the crew (Figure 5). The engineering team can simulate the ship's propulsion and energy system in different conditions and different operating models. The crew gets a support model to decide in advance with which speeds they should drive the ship on the next trip to be as efficient as possible.

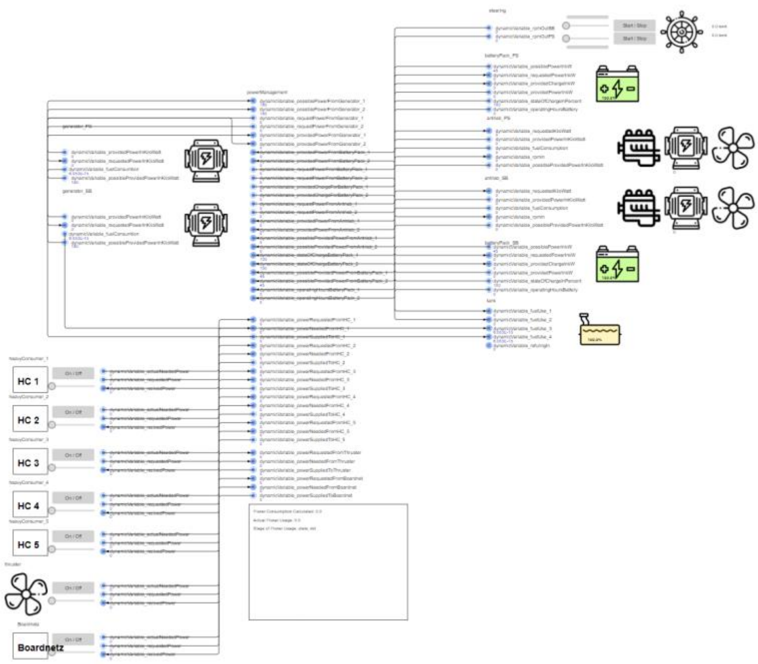

Figure 5 Propulsion Model System Dynamics

5.8 Fourth Iteration – Combination of Operations and Propulsion

The fourth iteration integrated the propulsion model into the operations model from iteration one. This inclusion benefits mainly two actors in the ecosystem. Starting from the Dispatch Manager with helping him to plan more ecological and economical routes for his ships. Another beneficiary is the owner as he will be able to develop new routes and business models that were not feasible before due to the lack of information.

6 Limitations and Future Research

This paper describes the theoretical concept of applying Digital Twins for decision support services in business operations. It is based on the decision chain consisting of the Digital Twin of the equipment and the Digital Twin of processes described in (Meierhofer & West, 2020) and applied here in the case study of the shipyard business, in which value is provided to specific actors by decision support services. The concept of the Digital Twin of the equipment and of processes could be successfully applied in this case study. However, this research did not yet systematically elaborate which type of business questions lend themselves for which specific concept of Digital Twin models.

Future research will provide a conceptual methodology for describing how service value creation for business operations is impacted by decision processes and how this concept can be taken to the next level by data-driven services. It will base this approach on the concept of the Digital Twin as a technical resource for informing these decision processes in complex and unpredictable environments.

This will enable to close the significant gap in the understanding, conceptualization, and design of value creation for business operations through data-driven service ecosystems, which is of strategic importance for research, business and society, as well as education.

References

Barbieri, C., West, S., Rapaccini, M., & Meierhofer, J. (2019). Are practitioners and literature aligned about digital twin. *26th EurOMA Conference Operations Adding Value to Society. Conference Paper*.

De Almeida, A. T., & Bohoris, G. A. (1995). Decision theory in maintenance decision making. *Journal of Quality in Maintenance Engineering*.

Dong, C.-S. J., & Srinivasan, A. (2013). Agent-enabled service-oriented decision support systems. *Decision Support Systems*, *55*(1), 364–373.

Holsapple, C. W. (2008). Decisions and Knowledge. In F. Burstein & C. W. Holsapple (Hrsg.), *Handbook on Decision Support Systems 1: Basic Themes* (S. 21–53). Springer. https://doi.org/10.1007/978-3-540-48713-5_2

Huynh, T. K., Barros, A., Bérenguer, C., & Castro, I. T. (2010). Value of condition monitoring information for maintenance decision-making. *2010 Proceedings-Annual Reliability and Maintainability Symposium (RAMS)*, 1–6.

Kowalkowski, C., & Ulaga, W. (2017). *Service strategy in action: A practical guide for growing your B2B service and solution business*. Service Strategy Press.

Kunath, M., & Winkler, H. (2018). Integrating the Digital Twin of the manufacturing system into a decision support system for improving the order management process. *Procedia CIRP*, *72*, 225–231.

Lightfoot, H., Baines, T., & Smart, P. (2013). The servitization of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations & Production Management*, *33*(11–12), 1408–1434.

Lusch, R. F., & Nambisan, S. (2015). Service innovation: A service-dominant logic perspective. *MIS Quarterly*, *39*(1), 155–176. https://doi.org/10.25300/MISQ/2015/39.1.07

Meierhofer, J., & West, S. (2019). *SERVICE VALUE CREATION USING A DIGITAL TWIN*. 11.

Meierhofer, J., & West, S. (2020). Data-driven Decision Support by Digital Twins in Manufacturing. *2020 7th Swiss Conference on Data Science (SDS)*, 53–54. https://doi.org/10.1109/SDS49233.2020.00019

Meierhofer, J., West, S., Rapaccini, M., & Barbieri, C. (2020). The Digital Twin as a Service Enabler: From the Service Ecosystem to the Simulation Model. In H. Nóvoa, M. Drăgoicea, & N. Kühl (Hrsg.), *Exploring Service Science* (S. 347–359). Springer International Publishing. https://doi.org/10.1007/978-3-030-38724-2_25

Oliva, R., & Kallenberg, R. (2003). Managing the transition from products to services. *International journal of service industry management*.

Osterwalder, A., Pigneur, Y., Bernarda, G., & Smith, A. (2014). *Value Proposition Design: How to Create Products and Services Customers Want*. John Wiley & Sons.

Paschou, T., Rapaccini, M., Adrodegari, F., & Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management*. https://doi.org/10.1016/j.indmarman.2020.02.012

Power, D. J. (2004). Specifying An Expanded Framework for Classifying and DescribingDecision Support Systems. *Communications of the Association for Information Systems*, *13*(1), 13.

Power, D. J. (2008). Decision support systems: A historical overview. In *Handbook on decision support systems 1* (S. 121–140). Springer.

Romero, D., Wuest, T., Harik, R., & Thoben, K.-D. (2020, Juli 12). *Towards a Cyber-Physical PLM Environment: The Role of Digital Product Models, Intelligent Products, Digital Twins, Product Avatars and Digital Shadows*.

Rowley, J. (2007). The wisdom hierarchy: Representations of the DIKW hierarchy. *Journal of Information Science*, *33*(2), 163–180. https://doi.org/10.1177/0165551506070706

Sala, R., Pezzotta, G., Pirola, F., & Huang, G. Q. (2019). Decision-Support System-based Service Delivery in the Product-Service System Context: Literature Review and Gap Analysis. *11th CIRP Conference on Industrial Product-Service Systems*, *83*, 126–131.

Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). *This Is Service Design Doing: Applying Service Design Thinking in the Real World*. O'Reilly Media, Inc.

Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of Manufacturing Systems*, *48*, 157–169. https://doi.org/10.1016/j.jmsy.2018.01.006

Thoben, K.-D., Wiesner, S., & Wuest, T. (2017). "Industrie 4.0" and Smart Manufacturing—A Review of Research Issues and Application Examples. *International Journal of Automation Technology*, *11*(1), 4–16. https://doi.org/10.20965/ijat.2017.p0004
Tukker, A., & Tischner, U. (2006). Product-services as a research field: Past, present and future. Reflections from a decade of research. *Journal of Cleaner Production*, *14*(17), 1552–1556. https://doi.org/10.1016/j.jclepro.2006.01.022
Vargo, S. L., & Lusch, R. F. (2008). From goods to service (s): Divergences and convergences of logics. *Industrial marketing management*, *37*(3), 254–259.
Vargo, S. L., Lusch, R. F., & Koskela-Huotari, K. (2018). *The SAGE Handbook of Service-Dominant Logic*. SAGE.
Weimer, D., Irgens, C., & Thoben, K.-D. (2016). Machine learning in manufacturing: Advantages, challenges, and applications AU - Wuest, Thorsten. *Production & Manufacturing Research*, *4*(1), 23–45. https://doi.org/10.1080/21693277.2016.1192517
Xia, L., Zhao, M., Rong, L., & Pang, R. (2009). Research on equipment maintenance decision system based on health management. *2009 8th International Conference on Reliability, Maintainability and Safety*, 653–657.
Zhou, R., Hu, Y., Xiao, S., & Wen, J. (2016). A multi-agent based decision–making approach for field service delivery of IPS2. *Procedia Cirp*, *47*, 228–233.