Understanding the Value of Digitized Products for Industrial Service Innovation

D I S S E R T A T I O N
of the University of St. Gallen,
School of Management,
Economics, Law, Social Sciences
and International Affairs
to obtain the title of
Doctor of Philosophy in Management

submitted by

Matthias M. Herterich

from

Germany

Approved on the application of

Prof. Dr. Walter Brenner

and

Prof. Dr. Tilo Böhmann

Dissertation no. 4775

Digitaldruckhaus GmbH, Konstanz 2018

The University of St. Gallen, School of Management, Economics, Law, Social Sciences and International Affairs hereby consents to the printing of the present dissertation, without hereby expressing any opinion on the views herein expressed.

St. Gallen, May 22, 2018

The President:

Prof. Dr. Thomas Bieger

Acknowledgements

This dissertation embodies the result of my research journey at the *Institute of Information Management* at *University of St.Gallen* in Switzerland and my time as a Visiting Scholar at the *Center for Design Research* at *Stanford University* in California, USA.

I would like to express my deepest appreciation to Prof. Dr. Walter Brenner for the creation of an outstanding overall working environment and numerous stimulating discussions in the context of this dissertation. I furthermore would like to thank Prof. Dr. Tilo Böhmann from *University of Hamburg* for his willingness to co-supervise this dissertation as well as for inspiring discussions throughout my dissertation journey.

Additionally, I would like to express my special appreciation to Prof. Dr. Falk Uebernickel, the project manager of *the Competence Center Industrial Service and Enterprise Systems (CC ISES)* for his invaluable cooperation and for providing the opportunity to conduct research and digital innovation projects with leading organizations in industrial manufacturing as well as in the software and IoT consulting industries within the context of *CC ISES*. Moreover, I would like to acknowledge with much gratitude the crucial role and support of all partner organizations that were involved in this research endeavour.

I would like to thank Barbara Rohner, Susanne Gmünder, Dr. Peter Gut, and Dr. Jochen Müller for their continuous support in organizational matters. I furthermore would like to thank my colleagues in St.Gallen for an unforgettable experience that formed some really close friendships. I also would like to thank my co-authors, with whom I have been privileged to work together in both paper projects as part of this dissertation project and beyond.

In addition to my activities at *University of St.Gallen*, I had the opportunity to continue my research activities as a visiting scholar at the *Center for Design Research (CDR)* at *Stanford University* in California, USA. I want to express deepest gratitude to all persons that were involved in making this happen. In particular, I want to thank Prof. Dr. Larry Leifer. Besides, I would like to thank Timothy C. K. Chou, PhD for stimulating discussions in Palo Alto that enabled me to see the results of my dissertation from an entirely new perspective.

Finally, I would like to express my deepest gratitude to my closest friends and my family for encouraging and supporting me throughout my dissertation journey.

Palo Alto, September 2017 Matthias M. Herterich

Table of Contents

Abstract

In the digital age, physical products are increasingly augmented with digital technology. In the course of this transition, innovation is no longer bound to the product functionality itself. Digitized products serve increasingly as a platform for service innovation. Specifically, digitized products can be leveraged to (1) incrementally increase efficiency or quality of existing services and (2) unlock potential for disruptive service offerings that would not be possible without digital technology. Particularly in product-oriented industries such as industrial manufacturing or the automotive sector, 'data-driven' or 'smart' services play an increasingly vital role for value co-creation. The trends of *servitization* and *digitization* have various implications on (1) the design of digitized products as service platforms, (2) the configuration of interdisciplinary organizational actors in service ecosystems, and (3) how value is co-created by these organizational actors. Existing research lacks a conceptual understanding and fails to explain this new phenomenon how 'smart' services emerge within product-oriented organizations and their interplay in service ecosystems.

This cumulative dissertation project addresses this research gap. Specifically, the first article provides a conceptual foundation for research on smart service systems and service innovation based on digitized products by untangling relevant concepts and theoretical perspectives on the phenomenon of interest. The second article identifies design principles for digitized industrial products by drawing on an Action Design Research (ADR) project. The third article focuses on the conceptualization of arising affordances of digitized products for service innovation by drawing on a revelatory case study. The fourth article of this dissertation focuses on service ecosystems and explains how smart service systems emerge. The service-dominant (S-D) logic and the affordance concept are used as theoretical foundation. The fifth article finally provides managerial guidance on how digitized products can be harnessed in a stepwise manner from the perspective of product-focused organizations as the dominating organizational actor in industrial service ecosystems.

This dissertation contributes to theory by (1) providing theory-backed design knowledge for digitizing physical products. Besides, it contributes to (2) understanding the value of digitized products for 'smart' services and (3) explores how 'smart' services emerge in product-focused organizations and service ecosystems. For managers, this dissertation provides actionable guidance on mastering the transition towards harnessing digitized products in innovative service offerings and adapting their business models accordingly.

Zusammenfassung

Physische Produkte werden zunehmend mit digitaler Technologie ausgestattet. Innovation beschränkt sich dabei nicht mehr ausschliesslich auf das Produkt selbst. Vielmehr werden digitalisierte Produkte verstärkt als Plattformen und damit Grundlage für Service-Innovation verstanden. So können (1) die Effizienz oder Qualität bestehender Services inkrementell optimiert oder (2) disruptive neue Services angeboten werden. Vor allem in produkt-fokussierten Industrien wie beispielsweise dem Maschinen- und Anlagenbau oder der Automobilindustrie gewinnen sogenannte ‚daten-getriebene' oder ‚smarte' Services an Bedeutung. Die gleichzeitige Digitalisierung und Service-Orientierung hat somit Implikationen auf (1) die Gestaltung digitaler Technologie im Kontext physischer Produkte, (2) die Konfiguration von Akteuren in Service-Ökosystemen sowie auf (3) das Zusammenspiel von Akteuren bei der Wertschöpfung. Existierender Forschung fehlt es an konzeptionellen Grundlagen für die Erklärung dieses Phänomens. Mit bestehenden theoretischen Perspektiven kann daher nicht erklärt werden, wie ‚smarte' Services in produkt-fokussierten Unternehmen und deren Ökosystemen entstehen.

Die vorliegende, kumulative Dissertation nimmt sich dieser Forschungslücke an. Konkret legt der erste Artikel die konzeptionellen Grundlagen und grenzt relevante Terminologie und theoretische Perspektiven gegeneinander ab. Der zweite Artikel identifiziert im Rahmen eines Action Design Research (ADR) Projekts Gestaltungsprinzipien für digitalisierte Industriegüter. Der dritte Artikel konzeptualisiert mögliche Nutzenpotentiale digitalisierter Industriegüter. Der vierte Artikel dieser Dissertation untersucht unter Zuhilfenahme der ‚Service-dominant (S-D) logic' sowie dem Affordance-Konzept, wie smarte Servicesysteme in Service-Ökosystemen entstehen. Der fünfte Artikel leistet schliesslich einen praktischen Beitrag, indem er konkrete Handlungsempfehlungen für die stufenweise Nutzung digitalisierter Industriegüter im industriellen Servicegeschäft ausspricht.

Der theoretische Beitrag der vorliegenden Dissertation liegt in (1) theoriegestütztem Gestaltungswissen für mit digitaler Technologie ausgestatteten Produkten. Darüber hinaus trägt die Dissertation zum (2) Verständnis des Wertes digitalisierter Produkte für ‚smarte' Services und (3) deren Entstehung in produktorientierten Organisationen und Service-Ökosystemen bei. Aus praktischer Perspektive leistet diese Dissertation einen Beitrag zum besseren Verständnis des Wandels produktorientierter Unternehmen, welche ihr traditionelles, analoges Produktgeschäft durch die Digitalisierung ihrer Produkte mit innovativen, service-orientierten Geschäftsmodellen sukzessive ersetzen.

Research Summary

Motivation

In the digital age, physical products are increasingly augmented with digital technology. In the course of this transition, innovation is no longer bound to the product functionality itself. Instead, digitized products are understood as platforms for service innovation (Barrett et al. 2015; Lusch and Nambisan 2015). Specifically, digitized products can be leveraged to (1) incrementally increase efficiency or quality of existing services and (2) unlock potential for disruptive service offerings that would not be possible without digital technology (Barrett et al. 2015).

Particularly in product-oriented industries such as industrial manufacturing or the automotive sector, emergent 'data-driven' or 'smart' services gain in importance to co-create value and serving the customers' needs (Porter and Heppelmann 2014, 2015; Maglio 2015; Medina-Borja 2015). Eventually, this transformation disrupts established business models, as it allows a transition from product sales to integrated product-service offerings (Neely 2008; Ulaga and Reinartz 2011; Lerch and Gotsch 2015). The term *servitization* was coined to describe this transition (Ulaga and Reinartz 2011; Lightfoot et al. 2013). Despite the myriad opportunities for service innovation, product-oriented organizations struggle in (1) making adequate technical decisions regarding the design of digitized products that serve as the foundation for service innovation. Furthermore, they face the challenge to (2) identify and conceptualize innovative use potentials and (3) ultimately harness digitized products in innovative service offerings (Yoo 2013; Porter and Heppelmann 2014, 2015; Barrett et al. 2015).

Besides these managerial challenges, the trends of *digitization* and *servitization* also gained scholarly attention. Research in this context, however, is at its infancy. Three major research gaps can be identified that are addressed by the dissertation at hand.

First, existing literature on product innovation and the traditional goods-dominant logic (Vargo et al. 2008) fail to explain value co-creation in interwoven service systems with various actors and the emergence of smart service systems (Fichman et al. 2014; Barrett et al. 2015; Vargo et al. 2015; Beirão et al. 2017; Vargo and Lusch 2017). Thus, novel theoretical perspectives are required that allow interdisciplinary research focusing on systematic service innovation based on digital technology (Barrett et al. 2015; Breidbach and Maglio 2016) and arising smart service systems (Maglio 2015; Medina-Borja 2015; Vargo and Lusch 2017).

Second, Böhmann, Leimeister, and Möslein (2014) likewise argue that service systems increasingly rely on digital technology. Thus, the proper design of digitized products gains in importance. This calls for research on the design of digitized products considering the requirements arising from potential product uses in smart service systems (Yoo 2013; Lyytinen et al. 2015).

Third, innovation related to digitized products goes beyond their digital and physical materiality (Lusch and Nambisan 2015; Vargo and Lusch 2017). Actor engagement in interdisciplinary service ecosystems is required to integrate complementing resources and eventually co-create value for beneficiaries by drawing on digitized products as central and shared resources (Breidbach and Maglio 2016; Storbacka et al. 2016; Vargo and Lusch 2017). Research that explores how digitized products can be exploited in smart service systems is needed to understand the emergence of service innovation at both an organizational and service ecosystem level and shape service innovation and smart service systems in the digital age (Ng 2014; Böhmann et al. 2014; Barrett et al. 2015; Breidbach and Maglio 2016; Beirão et al. 2017).

Addressing these research gaps and managerial challenges, the following overarching research question can be formulated:

How can digitized products be designed and leveraged to co-create value among organizational actors in interdisciplinary service ecosystems and afford innovative service offerings?

Structure of this dissertation

The overarching research question of the cumulative dissertation at hand can be broken down into three research questions (RQ). Figure 1 on the following page provides an overview on how the three RQs intertwine with the five articles of this dissertation.

RQ 1: *How can (1) digitized products and (2) related innovation be conceptualized, and how do the identified conceptualizations contribute to empirical and design-oriented research?*

The first research question sets the stage and provides the theoretical and conceptual foundations for this dissertation and research in the area of interest. Corresponding *Article I* aims at conceptualizing digitized products, related innovation as well as the relationship between these two elements. It adapts an analysis framework geared towards the structural nature of theories in information systems research (Gregor 2006; Gregor and Jones 2007). Four research streams that conceptualize digitized products and related

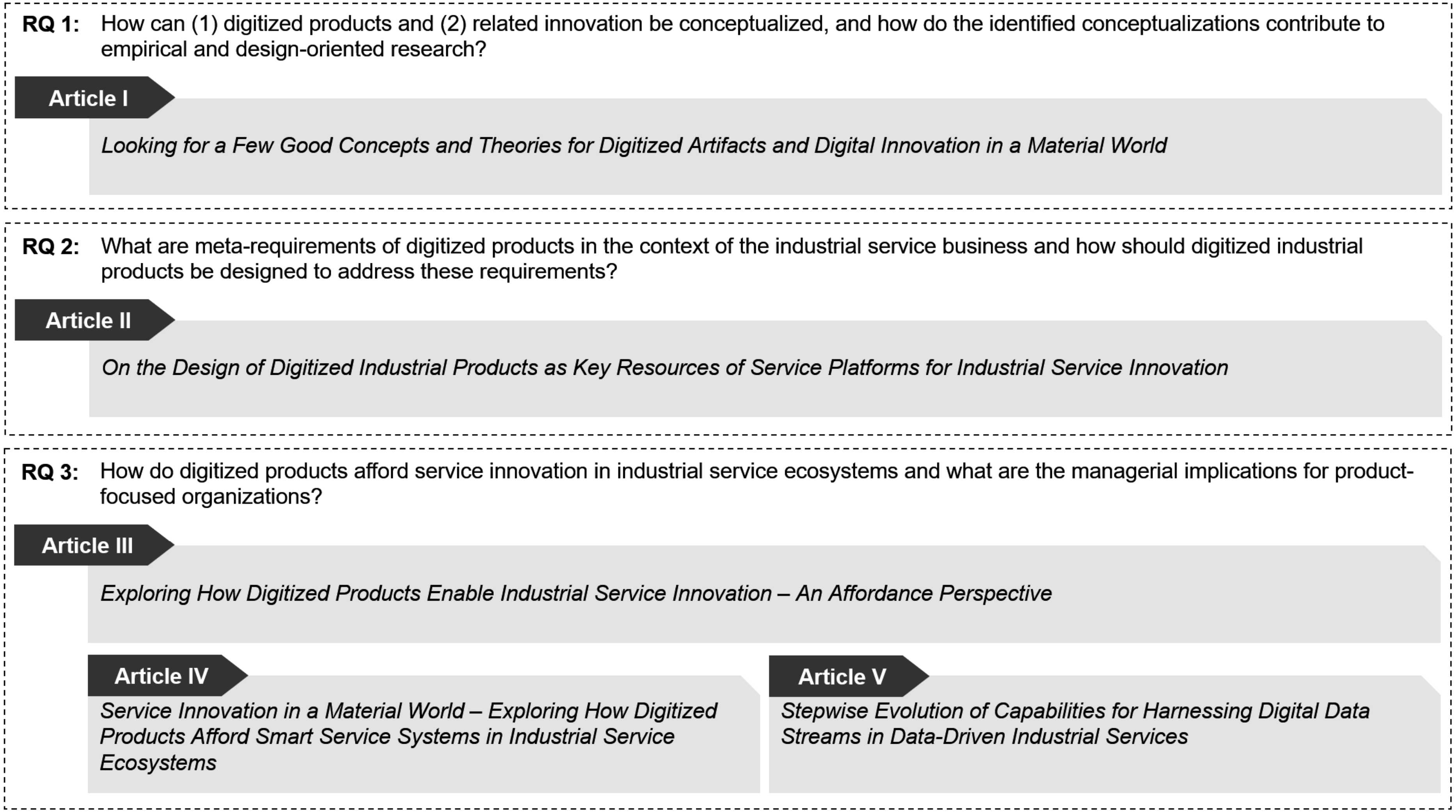


Figure 1. Overview of dissertation structure and constitutive articles

innovation are identified by drawing on the methodology of a systematic literature review (Webster and Watson 2002; Rowe 2014). The four research streams, namely “Ubiquitous and pervasive computing”, “Digital product innovation and digitized products”, “Digitized service innovation”, and “Digitized product service systems” are discussed in terms of their applicability for research on digitized products and related digital innovation. Recommendations for scholars are derived regarding how identified conceptualizations can be utilized and when their application is most suitable. Furthermore, ambiguities and blind spots in the existing body of knowledge are revealed as potential avenues for further research are pointed out. The findings related to RQ 1 provide the foundation for both empirical and design-oriented research in the context of digitized products and related innovation.

RQ 2: *What are meta-requirements of digitized products in the context of the industrial service business and how should digitized industrial products be designed to address these requirements?*

The second research question focuses on the design of digitized industrial products as the foundation for innovative service offerings in the specific context of industrial manufacturing. The generative capacity of digitized products impedes to come up with a comprehensive list of requirements addressing the “whole design” (Yoo 2013, p. 230) of digital technology ex ante. The term generativity describes this capacity of (digital) technology to be malleable by diverse groups of actors in unanticipated ways (Zittrain 2006). Existing work lacks design knowledge for generative digitized products (Yoo et al. 2010). This research gap and RQ 2 are addressed by means of a 2.5-year Design Science Research (DSR) project (Hevner et al. 2004; Peffers et al. 2007) with an industrial forklift manufacturer, a software company, and an IoT consultancy. Specifically, the project applied the Action Design Research (ADR) research methodology (Sein et al. 2011). The result of the ADR project are six meta-requirements that arise from characteristics of the industrial service business and nine evaluated design principles of digitized industrial products considering the characteristics of the industrial service business.

RQ 3: *How do digitized products afford service innovation in industrial service ecosystems and what are the managerial implications for product-focused organizations?*

The third research question finally focuses on the use potentials of digitized products in the context of the industrial service business and their actualization in interdisciplinary service ecosystems. So far, research on digital product innovation and digitized products lacks in an in-depth understanding of the emergence of usage potentials of digit-izedproducts in smart service systems (Zittrain 2006; Yoo et al. 2010, 2012; Ng 2014; Medina-Borja 2015; Vargo and Lusch 2017). RQ 3 is addressed by three interdependent articles that share an affordance perspective. Affordances describe the usage potentials of a technology and are defined as "the potential for behaviors associated with achieving an immediate concrete outcome and arising from the relation between an artifact and a goal-oriented actor or actors" (Strong et al. 2014, p. 12).

Article III introduces the affordance perspective that serves as the foundation to answer RQ 3. It furthermore proposes a framework to conceptualize affordances that arise based on digitized products in the context of innovative service systems. The framework is instantiated for *Performance-based contracting of industrial products* as an exemplary affordance of digitized industrial products in the industrial service business.

Article IV explores how digitized products afford smart service systems in industrial service ecosystems. It is rooted in a revelatory case study with 47 semi-structured interviews from an archetypical industrial service ecosystem, comprising an original equipment manufacturer, a maintenance, repair & overhaul organization, an analytics organization, and a product operator. The article identifies three classes of affordances and explains how *shared*, *organizational*, and finally *collective* affordances are concatenated in a stepwise manner before smart service systems emerge. Furthermore, shared institutions and institutional work are identified as crucial elements for the emergence of collective affordances and developing them towards smart service systems.

Article V finally contextualizes the scholarly findings by taking a practitioners' perspective with the goal to address the managerial challenges of the phenomenon of interest. It outlines a stepwise evolutionary path for the industrial service business by taking the perspective of product-focused organizations as the dominant actor in industrial service ecosystems. The article provides actionable managerial guidance of developing and harnessing digitized products in the industrial service business.

Scientific and managerial contribution

This dissertation contributes to the theoretical body of knowledge along the three research questions. Besides, the results with respect to RQ 2 and RQ 3 also provide relevant insights for practitioners.

First and most fundamentally, this dissertation lays out the conceptual foundations for research on the augmentation of physical products with digital technology and the resulting potentials for service innovation and smart service systems. *Article I* untangles relevant concepts and theoretical perspectives on the phenomenon of interest and provides an analysis framework and conceptual foundation for research on smart service systems for both this dissertation and further work. The service-dominant (S-D) logic is introduced as a valid perspective for conducting research on service affordances of digitized products (Breidbach and Maglio 2016; Vargo and Lusch 2015, 2017).

Second, this dissertation project proposes evaluated design principles for industrial moving assets as a specific class of digitized industrial products (Article II). The evaluated principles constitute prescriptive design knowledge as "Type V: Theory for Design and Action" (Gregor 2006, p. 628) and serve as a first step toward a nascent Information Systems Design Theory (ISDT) to design digitized products as platforms for service innovation (Gregor 2006; Gregor and Jones 2007). Besides, the design principles might serve practitioners in industrial manufacturing as a blueprint to design digitized products that can be successfully leveraged for innovative service offerings in the growing industrial service business.

Third, this dissertation project contributes to a better understanding of affordances that arise from digitized industrial products and how smart service systems emerge in industrial service ecosystems. *Article III* provides a framework to conceptualize affordances in the context of the industrial service business that can be leveraged in further work. Practitioners could use this framework as a tool to conceptualize and evaluate potentials for service innovation and identify relevant aspects of these potentials for their industrial service business. Furthermore, it is explored how smart service systems emerge in interdisciplinary industrial service ecosystems *(Article IV)*. The results show that organizational actors draw on a fixed set of digitized product's material properties and leverage them in shared, organizational, and collective affordances. The recombination and stepwise evolution of shared and organizational affordances result in collective affordances that spark smart service systems that eventually allow to serve the needs of the beneficiary. *Article IV* condenses the practice-oriented implications with regard to RQ 3. It complements the scholarly implications of this dissertation by providing actionable guidance for managers in product-oriented organizations as they progress through an archetypical servitization and digitization journey.

References

Barrett, M., Davidson, E., Prabhu, J., and Vargo, S. L. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Quarterly* (39:1), pp. 135–154.

Beirão, G., Patrício, L., and Fisk, R. P. 2017. "Value cocreation in service ecosystems: investigating health care at the micro, meso, and macro levels," *Journal of Service Management*.

Böhmann, T., Leimeister, J. M., and Möslein, K. 2014. "Service Systems Engineering: A Field for Future Information Systems Research," *Business & Information Systems Engineering* (6:1), pp. 73–79.

Breidbach, C. F., and Maglio, P. P. 2016. "Technology-Enabled Value Co-Creation: An Empirical Analysis of Actors, Resources, and Practices," *Industrial Marketing Management* (56), pp. 73–85.

Fichman, R. G., Dos Santos, B. L., and Zheng, Z. E. 2014. "Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum," *MIS Quarterly* (38:2), pp. 329–353.

Gregor, S., and Jones, D. 2007. "The Anatomy of a Design Theory," *Journal of the Association for Information Systems* (8:5), pp. 312–335.

Gregor, S. 2006. "The Nature of Theory in Information Systems," *MIS Quarterly* (30:3), pp. 611–642.

Hevner, A. R., March, S. T., Park, J., and Ram, S. 2004. "Design Science in Information Systems Research," *MIS Quarterly* (28:1), pp. 75–105.

Lerch, C., and Gotsch, M. 2015. "Digitalized Product-Service Systems in Manufacturing Firms.," *Research Technology Management* (58:5), pp. 45–52.

Lightfoot, H., Baines, T., and Smart, P. 2013. "The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends," *International Journal of Operations & Production Management* (33:11–12), pp. 1408–1434.

Lusch, R. F., and Nambisan, S. 2015. "Service Innovation: A Service-Dominant (SD) Logic Perspective," *MIS Quarterly* (1:39), pp. 155–175.

Lyytinen, K., Yoo, Y., and Boland, R. J. 2015. "Digital Product Innovation within Four Classes of Innovation Networks," *Information Systems Journal* (26:1), pp. 47–75.

Maglio, P. 2015. “Editorial—Smart Service Systems, Human-Centered Service Systems, and the Mission of Service Science,” *Service Science* (7:2), pp. ii–iii.

Medina-Borja, A. 2015. “Editorial Column - Smart Things as Service Providers: A Call for Convergence of Disciplines to Build a Research Agenda for the Service Systems of the Future,” *Service Science* (7:1), pp. ii–v.

Neely, A. 2008. “Exploring the Financial Consequences of the Servitization of Manufacturing,” *Operations Management Research* (1:2), pp. 103–118.

Ng, I. C. L. 2014. *Creating New Markets in the Digital Economy*, Cambridge, England: Cambridge University Press.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. 2007. “A Design Science Research Methodology for Information Systems Research,” *Journal of Management Information Systems* (24:3), pp. 45–77.

Porter, M. E., and Heppelmann, J. E. 2015. “How Smart, Connected Products Are Transforming Companies,” *Harvard Business Review* (93:10), pp. 96–114.

Porter, M. E., and Heppelmann, J. E. 2014. “How Smart, Connected Products are Transforming Competition,” *Harvard Business Review* (92:11), pp. 64–86.

Rowe, F. 2014. “What Literature Review Is Not: Diversity, Boundaries and Recommendations,” *European Journal of Information Systems* (23:3), pp. 241–255.

Sein, M., Henfridsson, O., Purao, S., Rossi, M., and Lindgren, R. 2011. “Action Design Research,” *MIS Quarterly* (35:1), pp. 37–56.

Storbacka, K., Brodie, R. J., Böhmann, T., Maglio, P. P., and Nenonen, S. 2016. “Actor Engagement as a Microfoundation for Value Co-Creation,” *Journal of Business Research* (69:8), pp. 3008–3017.

Strong, D. M., Johnson, S. A., Tulu, B., Trudel, J., Volkoff, O., Pelletier, L. R., et al. 2014. “A Theory of Organization-EHR Affordance Actualization,” *Journal of the Association for Information Systems* (15:2), pp. 53–85.

Ulaga, W., and Reinartz, W. J. 2011. “Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully,” *Journal of Marketing* (75:6), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2015. “Institutions and Axioms: An Extension and Update of Service-Dominant Logic,” *Journal of the Academy of Marketing Science* (44:1), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2017. "Service-dominant logic 2025," *International Journal of Research in Marketing* (34:1), pp. 46–67.

Vargo, S. L., Maglio, P. P., and Akaka, M. A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145–152.

Vargo, S. L., Wieland, H., and Akaka, M. A. 2015. "Innovation through institutionalization: A service ecosystems perspective," *Industrial Marketing Management* (44), pp. 63–72.

Webster, J., and Watson, R. T. 2002. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," *MIS Quarterly* (26:2), pp. xiii–xxiii.

Yoo, Y., Boland, R. J., Lyytinen, K., and Majchrzak, A. 2012. "Organizing for Innovation in the Digitized World," *Organization Science* (23:5), pp. 1398–1408.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724–735.

Yoo, Y. 2013. "The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research?," *Journal of the Association for Information Systems* (14:5), pp. 227–236.

Zittrain, J. 2006. *The Future of the Internet and How to Stop it*, New Haven, CT: Yale University Press.

A – **Article I**

Herterich, M.M. and Mikusz, M. (2016). “Looking for a Few Good Concepts and Theories for Digitized Artifacts and Digital Innovation in a Material World”. Completed Research Paper In: *Proceedings of the 37th International Conference on Information Systems (ICIS)*. Dublin, Ireland.

Looking for a Few Good Concepts and Theories for Digitized Artifacts and Digital Innovation in a Material World

Matthias M. Herterich
University of St.Gallen
9000 St.Gallen, Switzerland
matthias.herterich@unisg.ch

Martin Mikusz
University of Stuttgart
70174 Stuttgart, Germany
martin.mikusz@gsame.uni-stuttgart.de

Abstract

Physical objects get increasingly augmented with digital technology resulting in digitized artifacts and digital innovation. We adapt an analysis framework geared towards the structural nature of theories in IS research to investigate how digitized artifacts, digital innovation, and the relationship between the two are conceptualized. We identify and juxtapose research on 1) 'ubiquitous and pervasive computing', 2) 'digital product innovation and digitized products', 3) 'digitized service innovation', and 4) 'digitized product service systems' as four research streams that conceptualize digitized artifacts and related innovation. We discuss how the individual research streams contribute to the body of knowledge by recommending how existing concepts can be utilized and when their application is most suitable. We furthermore reveal ambiguities and blind spots as potential avenues for further research. For scholars, our work provides guidance in choosing an adequate theoretical foundation for research on digitized artifacts and digital innovation.

Keywords: Digitalization, digitized artifacts, digitized products, innovation, digital product innovation, service innovation, service-dominant logic, systematic literature review.

Introduction

Against the backdrop of digitization, physical artifacts such as consumer and industrial products get increasingly augmented with digital technology and connected with their environment. A study that focuses on the 'Internet of Things' estimates that there will be 26 billion digitized artifacts installed by 2020 (Van der Meulen 2015). *Digitized artifacts* are characterized by both digital and physical materiality. 'Connected cars' are an example of such digitized artifacts. The physical materiality of the vehicle is supplemented by digital technology that connects the vehicle with transportation infrastructure and other vehicles. In contrast to this focus of the paper at hand, *digital* artifacts (e.g., digital music streams) are characterized by a purely digital materiality (Kallinikos et al. 2013) and excluded in our work. Besides the traditional functionality of physical artifacts (e.g., cars afford mobility), digitized artifacts afford innovative value-added services. Live traffic information and other comfort services are examples in the context of 'connected cars'. Depending on the use context, digitized artifacts offer myriad opportunities for *digital innovation.* Digital innovation goes beyond traditional product functionality of the physical artifact and traditional mechanisms in innovation literature (Barrett et al. 2015). Since the trend of augmenting physical artifacts with digital technology exists for quite some time, broad and diverse research in various domains has built up wide and diverse scholarly knowledge, taking different perspectives and focusing on various aspects of the phenomenon of interest (Fichman et al. 2014). Whereas early conceptualizations of digitized artifacts primarily focus on the incorporation of traditional computing into new environments and contexts (Lyytinen and Yoo 2002), most recent attempts to conceptualize digitized artifacts focus on their design (Yoo 2010; Yoo et al. 2010) and, above all, their generative capacity to pivot business models of organizations or even entire industries (Yoo 2010; Yoo et al. 2010; Porter and Heppelmann 2014, 2015). At the same time, the related digital innovation is understood differently depending on the respective underlying theories and the conceptualization of digitized artifacts.

In their seminal article, Fichman et al. (2014) distinguish between digital innovation *outcome* and digital innovation *process.* The paper at hand focuses on digitized artifacts and related innovation and thus on the digital innovation *outcome*. The digital innovation *process* is not addressed. Because of the disparate, complex, and interdisciplinary body of knowledge on digitized artifacts and digital innovation, researchers face difficulties in overseeing existing literature. They struggle with staying on top of things when choosing the right concepts and theories for their particular research focus. So far, no guidance exists for choosing adequate theoretical foundations to 'stand on the shoulders of giants'. Being not able to use consistent concepts and adequate theoretical perspectives bears the risk that the IS community is not able to contribute effectively to the scientific discourse on digitized artifacts and digital innovation. Furthermore, practitioners feel intimidated and overwhelmed by the multitude of theoretical foundations because of their lack of theoretical background knowledge. Crossing the boarders of the IS discipline, we believe that the time is right to recap existing interdisciplinary research aiming to consolidate knowledge and juxtapose different perspectives the phenomenon of digitized artifacts and related innovation. Thus, we pose the following research question: *How does research conceptualize (1) digitized artifacts and (2) related innovation based on this phenomenon, and how do the identified conceptualizations contribute to empirical and design-oriented research?*

To answer the research question, we develop and utilize an analysis framework that enables us to investigate and contrast existing literature on the phenomenon of interest. This study, however, goes beyond just classifying or mapping the field. By applying the analysis framework to publications obtained from a systematic literature review, we identify four research streams. Publications in each research stream share the same perspective on the phenomenon of interest. This paper helps the IS discipline to make novel contributions on digital innovation by providing guidance on utilizing existing conceptualizations in future research and revealing blind spots as well as ambiguities that have prevented advancing theory. The remainder of this paper is structured as follows: In the next section, we present our analysis framework along with the research method for the review of the existing body of knowledge. We then apply the analysis framework and walk through the identified research streams by presenting the results of our analysis. Key findings are instantiated within the context of an illustrative example. We discuss our results in that we reveal ambiguities and blind spots in the present conceptualizations, and derive recommendations that provide guidance for future scholarly work that involves digitized artifacts and related innovation. Finally, we conclude by discussing implications and limitations of our work, and presenting avenues for future research.

Analysis Framework and Research Method

As proposed by Webster and Watson (2002), we begin with clarifying the scope of our investigation. The overall goal of this paper is to provide an overview of different perspectives on the phenomenon of interest. We do neither aim at providing our own perspective, nor integrating existing perspectives. In particular, we focus on three aspects. First, we investigate how research conceptualizes *digitized artifacts.* Second, we focus on the conceptualization of *innovation* based on digitized artifacts. Third, we investigate the present statements of *relationship between these two elements*. In analyzing existing research, we opted for drawing on the work of Gregor (2006) and Gregor and Jones (2007), who elaborate on the structural nature of theories in IS research. Both contributions adopt the same, rather broad view of theory encompassing what might be termed elsewhere models, frameworks, or simple bodies of knowledge (Gregor 2006; Jones and Gregor 2007). The dimensions of the resulting analysis framework are generic enough to allow us investigating different kinds of theory, yet focus on the core elements and relationships of our phenomenon of interest. Drawing on the generic elements of a theory as guiding structure allows us to take into account different levels of abstraction and granularity of theoretical knowledge in investigated literature. Table 1 provides an overview of our analysis framework.

Table 1. Analysis Framework based on Gregor (2006) and Gregor and Jones (2007)

Dimension	*Description*
Underlying theories	The underlying theory or theories on a higher level of generalization that give(s) a basis and explanation for the considered body of knowledge or theory.
Purpose and scope	The purpose and scope specifies the "What the theory is for", including boundaries of the theory as well as limits of generalizations.
Constructs	Constructs refer to the representations of the entities of interest in the theory. Based on our research question, we focus on (1) constructs for the *digitized artifact*, and (2) constructs for the phenomenon of *innovation*.
Statements of relationship	Describe the relationships between the constructs. Based on our research question, we focus on statements of relationship between constructs for the digitized artifact and constructs that conceptualize the related innovation.
Components contingent on theory purpose	The four primary goals of theory discerned are *analysis and description, explanation, prediction,* and *prescription*. The components above are common to all theory. Moreover, theories for explanation include causal explanations, theories for prediction include testable propositions, theories for design and action include prescriptive statements.

We chose the described approach over compiling a concept matrix (Webster and Watson 2002), which we consider as being too generic with respect to our research question. We furthermore decided against drawing on existing theories or frameworks on digitized artifacts and related innovation, as this would obstruct our unbiased perspective on the various streams of research in the existing body of knowledge. Overall, the work of Gregor (2006) and Gregor and Jones (2007) is well-established and widely used in other reviews of literature (e.g., Belanger and Crossler 2011). Our analysis follows three consecutive stages that are depicted in Figure 1.

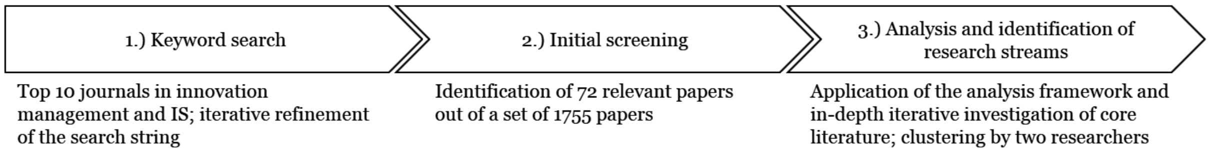


Figure 1. Process of Literature Analysis

In the first stage (*keyword search*), we identified publications that contain conceptualizations of digitized artifacts and/or related innovation. We ensure reproducibility of the results by adapting a structured and well-established approach (Webster and Watson 2002). Since the interdisciplinary nature of the phenomenon of interest prevented us from identifying literature exhaustively, we chose a “purposive sample” ensuring a representative coverage of the topic (Rowe 2014). This work furthermore aims for a general understanding rather than an exhaustive identification of literature that is performed mechanically and provides an illusory complete picture (Rowe 2014). We focus on the disciplines of innovation management and IS as two core disciplines potentially dealing with digitized artifacts and related innovation. Our search covers leading journals with a high reputation for quality (Webster and Watson 2002). With respect to innovation management literature, we consider the top 10 journals in the field (Linton and Thongpapanl 2004). We furthermore opted for the top 10 journals in the IS domain (Lowry et al. 2013). With this IS sample, we go beyond the AIS Senior Scholars’ basket of journals (top 8). Since *‘Decision Support Systems’* does not address our topic, we replaced it by the ‘*Information & Management*’ outlet. We furthermore added the *Proceedings of the International Conference of Information Systems (ICIS)* as a quality conference outlet. With this, we take account for the long review cycles and the availability of high quality conferences in the IS domain. We included publications that explicitly conceptualize digitized artifacts and/or innovation based on digitized artifacts. To capture relevant publications that potentially meet our criterion for inclusion, we used a quite broad, compound search string for the initial screening based on the publications‘ titles and abstracts. The search string was generated by combining pertinent terms such as *digit*, technolog*, enabled, innovat*, service, smart, convergen**. We opted for using a broad search string and going beyond the IS discipline to minimize bias from our idiosyncratic knowledge and institutional contexts (Shepherd and Sutcliffe 2011). The timeframe was limited to papers starting from 1990. The compound search string resulted in a total number of 820 papers in IS outlets, and 935 papers in innovation management outlets.

In the second stage (*initial screening*), two scholars independently screened titles and abstracts of all obtained results on actually involving a conceptualization of digitized artifacts and/or related innovation. In ambiguous cases, full texts were considered in addition for initial screening. Given the broad search string, we excluded a significant number of papers that did not meet the above-mentioned criterion. For example, papers were excluded that focus on the digitization of processes, production, platforms, or administration. We furthermore excluded research-in-progress papers, interviews, summaries of panel discussions, short papers, and research or practice commentaries. Taking also into account papers obtained from forward and backward search, we obtained a set of 72 papers for in-depth analysis.

In the third stage (*analysis and identification of research streams*), we applied our analysis framework and analyzed full texts with regard to the research question. As our research question is highly interpretative and addresses an emerging yet interdisciplinary field of research, we thoroughly assessed the publications qualitatively rather than classifying them in a mechanical way (Rowe 2014). For analyzing publications, we opted for an iterative approach since "it has been widely acknowledged that theorizing is an iterative process" (Shepherd and Sutcliffe 2011, p. 362). Publications were coded based on the identification of shared ways to conceptualize our phenomenon of interest. The coding was performed individually by two researchers. To ensure an aligned understanding, the usage of the analysis framework and interim results were discussed in three full-day workshops spread evenly over the coding period. During the coding, further articles were removed due to a lack of explicit or implicit statements with regard to the dimensions of our analysis framework. Table 4 in the appendix provides a detailed overview of the removed publications in this stage. Finally, we identified four research streams as a guiding structure in the disparate body of knowledge.

We clarify the distinct conceptualizations of digitized artifacts and related innovation by drawing on an illustrative example in the context of connected cars – the 'In-Car-Delivery' scenario (Ewing 2015): Based on timely information on the location of connected cars, a postman can approach a connected car and temporary unlock it to deliver packages in its trunk. As part of this mobile delivery service, customers can track the delivery activities on their smartphones. We pick the case since (1) it is an intuitive illustrative example that is easily understood without additional need for explanation. In line with our research question, this example (2) well illustrates the differences of the distinct conceptualizations of the digitized artifact (i.e., the connected car) and a specific self-contained innovation related to the digitized artifact along the different research streams. Finally, we (3) have profound knowledge on innovative connected car services from previous research projects on product and service innovation in the field of connected cars. Close collaboration with 19 senior managers from various original equipment manufacturers (OEMs) within the course of a Delphi study on connected car business models, and an in-depth document analysis furnishes us with knowledge in this field. In another study with more than 80 participants, we investigated value propositions of connected car services from a customer perspective. Thus, we feel confident in using the scenario introduced as an illustrative example throughout this paper. By instantiating the different conceptualizations from the identified research streams, the illustrative example helps to concretize the findings from the review of literature and sharpen the understanding of our phenomenon of interest.

Results

Digitized artifacts and related innovation are conceptualized differently in diverse research streams within innovation management and IS literature. Table 2 on the following page provides an overview of four different conceptualizations along the dimensions of our analysis framework. First, an early understanding of digitized artifacts is rooted in research on ubiquitous and pervasive computing (Stream 1: *Digitized artifacts and related innovation in research on ubiquitous and pervasive computing* – 6 core publications). Second, research on digital product innovation and digitized products focuses on the design and material properties of digitized products (Stream 2: *Digitized artifacts and related innovation in research on digital product innovation and digitized products* – 8 core publications). Third, research taking the S-D logic perspective aims at generating an understanding on how digitized artifacts understood as service platforms are leveraged for value creation (Stream 3: *Digitized artifacts and related innovation in research on digitized service innovation* – 3 core publications). Fourth, mainly practitioner-oriented literature was identified that adopts concepts dealing with the product-service transition and sets a close link between digitized artifacts and business model innovation (Stream 4: *Digitized artifacts and related innovation in research on digitized product service systems* – 6 core publications).

Digitized artifacts and related innovation in research on ubiquitous and pervasive computing

Underlying theories. Research that addresses the understanding of digitized artifacts and innovation from the perspective of ubiquitous and pervasive computing focuses on the value that arises from the application of information technology in a business context

Table 2. Overview of the Identified Research Streams along the Dimensions of our Analysis Framework

Dimension	*Characteristic*	*Ubiquitous and pervasive computing*	*Digital product innovation and digitized products*	*Digitized service innovation*	*Digitized product service systems*
Underlying theories		Value systems to conceptualize value and value creation.	Decomposable systems theory, modularization, Schumpeterian innovation, theory of affordances, generativity concept.	Service-dominant (S-D) logic.	Theories and concepts dealing with the product-service transition: servitization, product service systems, integrated solutions.
Purpose and scope		Aims at understanding the incorporation of traditional computing tasks into environments that has so far been traditionally detached from computing.	Aims at developing an understanding of the architecture of physical objects that get augmented with digital technology.	Aims at providing a framework to understand how value co-creation is enabled by digitized service innovation following S-D logic.	Aims at conceptualizing the shift towards selling outcomes instead of products within the product-service transition.
Constructs	Digitized artifact	Focus on properties of the environment of ubiquitous and pervasive computing.	Focus on material properties of digitized artifacts; layered modular architecture as product architecture.	Digitized artifact as service platform; digital materiality of the artifact (service platform) as operand and operant resource (dual role).	Digitized artifact as digitized product service system defined by certain attributes, capabilities, and architectural components.
	Innovation	Business value and innovation based on the level of embeddedness and the level of mobility.	Digital innovation as novel combination of digital and physical elements; demarcation from product innovation (Schumpeterian understanding).	Innovation as service innovation; innovation in terms of increased value-in-context rather than in terms of technological product invention.	Innovation as business model innovation that digital technology enables or at least stimulates.
Statements of relationship between the digitized artifact and innovation		The higher the level of embeddedness and mobility, the more a case represents an innovation in ubiquitous and pervasive computing.	Connections between layered modular architecture describing the internal structure of digitized artifacts.	Digital materiality of the artifact seen as (a) operand resource facilitates innovation; (b) operant resource triggers innovation.	Digitization of product service systems enables entirely new business models.
Components contingent on theory purpose		Descriptive statements, no causal relationships; theory for analyzing.	Design elements; central prescriptive statement: use layered modular architecture as foundational model for the design of digitized artifacts.	Central prescriptive statements: design digitized artifacts as service platforms (with layered-modular architecture); consider digital materiality especially as operant resource.	Prescriptive statements that are often not derived from causal explanations or testable propositions.

in pervasive ubiquitous settings (Jonsson et al. 2008; Lansiti and Lakhani 2014). It therefore draws on the concept of value systems introduced by Porter (1985). For the conceptualization of the digitized artifact, underlying theories are not referred explicitly.

Purpose and scope. Advances in technology and the trend of miniaturization have increased the level of embeddedness and mobility of digital technology into objects and environments. This phenomenon is conceptualized as ubiquitous computing (Lyytinen and Yoo 2002). Research in this field focuses on the incorporation of traditional computing tasks into environments that traditionally have been detached from computing (Lyytinen and Yoo 2002). Depending on the level of embeddedness and the level of mobility, pervasive computing (embeddedness: high; mobility: low), and mobile computing (embeddedness: low; mobility: high) exist as related conceptualizations that can be demarked against traditional business computing. The term pervasive computing emphasizes that computing and digital technology become pervasively integrated into hitherto purely physical objects (Kourouthanassis et al. 2010; Lyytinen and Yoo 2002). Research on ubiquitous and pervasive computing are first attempts to address the incorporation of digital technology into physical objects from a scientific perspective. Primary scope are benefits and value of digital technology in a business context. The research particularly focuses on identifying adequate usage contexts (Kourouthanassis et al. 2010) and deals with the value of the vanishing yet pervasive nature of computing in knowledge work at an individual and organizational level. Applications of the paradigm are sparse at its inception in theory. In contrast to the concepts of ubiquitous and pervasive computing, the nomadic computing concept focuses on the environment as a "heterogeneous assemblage of interconnected technological and organizational elements, which enables the physical and social mobility of computing and communication services between organizational actors both within and across organizational boundaries" (Lyytinen and Yoo 2002, p. 378). With the emergence of condition monitoring technology in industrial machinery and heavy equipment, the concepts related to ubiquitous and pervasive computing got renewed interest (Jonsson et al. 2008). Current research aims at conceptualizing the value that arises from ubiquitous and pervasive computing cases (Lansiti and Lakhani 2014).

Constructs for the digitized artifact. In particular, pervasive computing refers to technology embedded in products and the environment (Lyytinen and Yoo 2002). In this context, Dey (2001) identifies *identity*, *location*, *status*, and *time* as key data that occur in ubiquitous and pervasive computing contexts. Furthermore, descriptive frameworks exist that delineate the dimensions of pervasiveness for information systems, namely *mobility*, *interactivity*, *heterogeneity*, and *contextual awareness* (Kourouthanassis et al. 2010). Due to the focus on contextual factors, explicit conceptualizations of the digitized artifacts itself are not provided.

Constructs for innovation. To understand how value is created by embedded and mobile technology, this research stream draws on the concept of value systems introduced by Porter (1985). Value streams focus on value creation within a single organization and across individual organizations within networked business settings. Hence, ubiquitous computing as technology is viewed from a value-creation perspective to better understand innovation (Jonsson et al. 2008). For instance, Jonsson et al. (2008) draw on this logic to explain how remote diagnostic systems allow manufacturing firms to become remote service providers. Besides the technical focus, the authors provide first insights on how condition monitoring technology as a specific type of ubiquitous computing changes value creation and fosters innovation in the industrial service business. In particular, they illustrate how ubiquitous computing creates value when implemented in industrial products in the field instead of just in the context of individuals (i.e., leveraging mobile technology). Likewise, Kourouthanassis et al. (2010) draw on the concept of pervasiveness to investigate information technology embedded in the physical environment. They propose a taxonomical framework as a tool to assess the level of pervasiveness and thus innovativeness of information systems. With *ubiquity*, *diffusion*, and *contextual awareness* as three major dimensions of the framework, they provide prescriptive statements how to design pervasive information systems. Whereas Kourouthanassis et al. (2010) inform the design of pervasive IS, Jonsson et al. (2008) and Watson et al. (2011) focus on the value and innovation potential of technology in dedicated contexts.

Statements of relationship between the digitized artifact and innovation. Research that addresses the understanding of digitized artifacts and innovation from the perspective of ubiquitous and pervasive computing focuses on describing digital technology and the resulting value independently. The relationship between digitized artifacts and innovation is not explicitly addressed in literature on ubiquitous and pervasive computing. However, the implicit understanding is that the higher the level of embeddedness and mobility, the more a case represents an innovation in ubiquitous and pervasive computing.

Components contingent on theory purpose. The proposed understanding of the digitized artifact and innovation in research from the perspective of ubiquitous and pervasive computing can be regarded as foundational theory for analyzing in terms of the five types of theory proposed by Gregor (2006). It largely focuses on describing and classifying characteristics of the phenomenon of interest without aiming to explain causalities or attempting predictive generalizations.

Illustrative example. The proposed conceptualization in this research stream applied to the connected car as a digitized artifact does not distinguish between (1) the fact that physical artifacts such as cars provide access to the internet and (2) the augmentation of physical artifacts with sensors, actuators, and connectivity resulting in a virtual representation of the artifact in the internet. Due to their high level of embeddedness and mobility, connected cars can be understood as a case of ubiquitous computing in the in-car-delivery scenario. Digital technology embedded in the car as a physical artifact is characterized by a high degree of mobility. This is the case since the following characteristics are met: extension of traditional computing boundaries (increased mobility and continuous connectivity of the connected car), invisibility and unobtrusiveness (concealment of digital material properties in the connected car from the users' consciousness), context-aware multi-modal interaction (interaction via mobile app or human interface in the car), and heterogeneity of pervasive artifacts (interoperable interface to allow connected cars of different OEMs to be used for the same offering) (Kourouthanassis et al. 2010). However, looking at the case by prospects of research on pervasive and ubiquitous computing, we would omit to conceptualize the innovation that is enabled by digital technology (i.e., package delivery in the trunk of connected cars) and solely focus on the technical phenomenon.

Digitized artifacts and related innovation in research on digital product innovation and digitized products

Underlying theories. The conceptual understanding of digitized artifacts and related innovation in this research stream rests on the work of Simon (1996) with the idea of nearly decomposable systems, Baldwin and Clark's (2000) work on modularization, as well as on the modular systems theory (Schilling 2000) and its evolution towards the generativity concept (Yoo 2010; Yoo et al. 2010). Generativity describes "a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain 2006, p. 1980). Based on this understanding, theory of affordances (Majchrzak and Markus 2013) is used as a theoretical lens to conceptualize the generative capacity and usage potentials of digitized artifacts that lead to product and service innovation (Yoo 2010; Yoo et al. 2010).

Purpose and scope. Research on digital product innovation and digitized products focuses on the characteristics and material properties of the physical and digital materiality of digitized products as a new combination (Yoo 2010, 2013, Yoo et al. 2012, 2010). Regarding the scope, special focus lies on the permeation of digital technology into our everyday activities and physical consumer artifacts that increasingly have embedded digital capabilities (Yoo 2010). The experiential computing research framework is a tool to test theories and build and evaluate digitized everyday artifacts (Yoo 2010). Experiential computing research furthermore suggests to also take into account desirability as an additional important criterion for evaluating the success of digital technology, besides the traditional dimensions for evaluation (Yoo 2010). Whereas research on experiential computing exclusively focuses on the context of our personal live (Yoo 2010), the concept of digital product innovation itself does not have any limitations in scope or focus, so also serves as a valid lens in an industrial context (Yoo et al. 2010).

Constructs for the digitized artifact. In contrast to traditional IS theories, the physical material properties of digitized artifacts become increasingly important. Recognizing this, Yoo (2010) identifies the need to develop design theories taking into account physical and digital materiality, and to validate their understanding through the construction and evaluation of innovative artifacts. Similar to early work in the field of pervasive computing (Kourouthanassis et al. 2010), literature on digital product innovation and digitized products proposes seven material properties (i.e., programmability, addressability, sensibility, communicability, memorizability, traceability, and associability) that describe the product characteristics as a result of digitization. The design of traditional products can be characterized as modular with linear and sequential production processes (Yoo et al. 2010; Yoo 2013). Product boundaries are fixed and individual components are nested in a single design hierarchy (Yoo et al. 2010). Products augmented with digital technology, however, follow the principles of the layered modular architecture. Individual components are loosely coupled through standardized interfaces that are shared among various actors; fluid product boundaries and meanings exist depending on the actor and use context, in which the product is embedded. The foundational product functionality is based on four layers of digitized products (Yoo et al. 2010). The *device layer* deals with physical machinery properties and logical issues at an operating system level. Examples are sensors that generate data on product operations. The *network layer* focuses on the physical aspects of data transmission. The *service layer* addresses application functionality enabling actions such as create, manipulate, store, and consume contents. Finally, the *contents layer* addresses digital content related to the digitized product. The layered modular architecture manifests two critical separations. First, the device and service layers are isolated because of the (re)programmability trait of digital technology. Second, the network layer is detached from the contents layer because of the homogenization of data (Yoo et al. 2010). Research on digital product innovation and digitized products aims to provide prescriptive guidance to rigorously develop and design digitized artifacts that are characterized by a high level of generativity (Zittrain 2006; Yoo 2010).

Constructs for innovation. In this research stream, innovation is understood in the Schumpeterian sense (Schumpeter 1934). Accordingly, digital innovation is defined as "the carrying out of new combinations of digital and physical components to produce novel products" (Yoo et al. 2010, p. 725). This understanding implies the delimitation of digital innovation from traditional product innovation (Henderson and Clark 1990) as an innovation continuum (Yoo et al. 2012). Whereas traditional product innovation aims at the modular product architecture, digital innovation is enabled by digital technology and goes beyond the physical materiality of the product. Leveraging digitized artifacts for digital innovation offers opportunities for incremental innovation as well as radical innovation (Hildebrandt et al. 2015; Jonsson et al. 2008; Lyytinen and Rose 2003). To further demarcate different kinds of digital innovation, Fichman et al. (2014) distinguish between digital *product*, *process*, and *business model* innovation. Besides the different kinds of digital innovation, a structuring process model comprising *discovery*, *development*, *diffusion*, and *impact* as four stages of digital innovation is introduced (Fichman et al. 2014). The model describes digital innovation as a process irrespective of the class of innovation and serves as a structuring device for digital innovation within the IS domain.

Statements of relationship between the digitized artifact and innovation. Digitizing physical objects gives them new properties that facilitate anticipated and unanticipated opportunities for digital innovation (Yoo et al. 2010). The foundation for digital innovation is digital technology that can be described by three unique characteristics, namely (1) reprogrammability, (2) homogenization of data, and (3) self-referential nature (Yoo et al. 2010). To explain how innovation based on digitized artifacts occurs, literature in this research stream states two mechanisms, namely *distributed innovation* and *combinatorial innovation* (Lyytinen et al. 2015; Yoo et al. 2012). First, the phenomenon of distributed innovation describes a shift of innovation activities towards the periphery of organizations (Lyytinen et al. 2015; Yoo et al. 2012). New forms of collaboration such as innovation challenges or innovation networks allow organizations to harness the creativity outside of the organizational boundaries and integrate heterogeneous knowledge (Lyytinen et al. 2015). Second, based on modularity and the combination of existing modules of digitized artifacts (Schilling 2000), combinatorial innovation arises as a new source of innovation (Yoo et al. 2012). The traditional logic of "simple modularity" (Henfridsson et al. 2014, p. 29), however, is considered as being outdated and no longer provides a sufficient theoretical framework to fully explain innovation (Yoo 2013). Instead, the generative capacity of digital technology (Henfridsson et al. 2014; Yoo et al. 2012, p. 1399) serves as an enabler for digital innovation. Generativity results from combining product information, product environment, and connectivity – referred to as digital convergence (Lyytinen et al. 2015; Tilson et al. 2010; Zittrain 2006). In particular, the dissociation between the individual layers of the layered modular architecture affords generativity (Zittrain 2006). Thus, building up a layered modular architecture is considered as a critical success factor for digital innovation. The concept of generativity helps to explain how a finite number of physical and digital material properties of digitized products can lead to the emergence of a seemingly infinite number of affordances. Resulting affordances and thus digital innovation represent new opportunities to create value based on the material properties of digitized products. Although existing research so far rather focuses on the identification of such affordances instead of their implementation (Herterich et al. 2016), first attempts exist that empirically verify the positive effect of digital product innovation on digital business model innovativeness (Hildebrandt et al. 2015; Piccinini et al. 2015).

Components contingent on theory purpose. In terms of the five types of theory proposed by Gregor (2006), research on digital product innovation and digitized products can be mainly regarded as theory for explaining. Research in this stream mainly aims at explaining how the generative capacity of digital technology affords digital innovation in myriad ways. Despite this classification, we can identify a move towards theory for design and action addressing the design of the artifact itself (causa formalis). First research exists that aims at identifying the principals behind a dominant design (Anderson and Tushman 1990; Clark 1985) and thus provides concrete guidance on the proper design of digitized artifacts (Hylving et al. 2012; Hylving and Schultze 2013; Yoo 2013). With respect to principles of implementation (causa efficiens), research that deals with the implementation of the design is in its infancy (Henfridsson et al. 2014; Lyytinen et al. 2015; Yoo et al. 2012).

Illustrative example. Instantiating the identified conceptualizations and mechanisms in our illustrative example reveals that the focus of this research stream lies on the digital materiality of digitized artifacts. Connected cars that are equipped with digital technology are characterized by programmability (new software modifies behaviors and functions), addressability (trunk can be opened remotely), sensibility (car is aware of its location and status such as driving or parking), communicability (car is online), memorizability (package delivery status is stored to be provided to the driver), traceability (geospatial data is made available to package delivery organization), and associability (car can be identified when postman approaches it). With regard to the internal structure of the material properties, the layered modular architecture can be applied to the illustrative example. The vehicle augmented with sensor technology such as GPS sensors and actuators that allow to unlock the doors remotely, represents the *device layer*. By means of the in-car bus system, communication protocols, and mobile internet infrastructure, the car is connected to a digital platform at the *network layer*. Representing the core of the *service layer*, a digital platform incorporates application logic for processing information of the owner of the car and its location. The service layer furthermore integrates location data of the mail van to optimize its delivery routes. Finally, the *contents layer* comprises all data that are displayed to the postman and the recipient of the package. For instance, the recipient can be notified on his mobile device that the package has been delivered successfully. This is realized by interfaces to mobile applications or push notification services on the smartphone of the car owner. The illustrative example demonstrates that the conceptualization of digitized artifacts in this research stream goes beyond the physical materiality of digitized products. The physical material properties of digital technology in the connected car case do not afford the delivery of packages in the trunk by themselves. Only the interplay between the individual layers in the modular layered architecture unleashes the generative capacity of digital technology depending on the dedicated use context.

Digitized artifacts and related innovation in research on digitized service innovation

Underlying theories. The research stream on digitized service innovation is rooted in S-D logic (Vargo and Lusch 2004, 2008, 2016). In the light of this perspective, service is understood as the common denominator of economic and social exchange, instead of representing an intangible product, i.e., a unit of output (Vargo et al. 2008). Hence, service provision is seen as a joint and reciprocal value co-creation process in which different actors integrate resources. In this collaborative and interactive process, the distinction between producer and consumer dissolves. Instead, the concept of value co-creation is utilized (Vargo and Lusch 2004). Actors involved in value co-creation form value co-creation networks (Lusch et al. 2010; Vargo and Lusch 2008) that S-D logic scholars recently have reconceptualized as service ecosystems (Lusch and Vargo 2014;

Lusch and Nambisan 2015). Value is understood in the sense of value-in-use and determined contingent upon the specific context of use (i.e., value-in-context). Physical goods involved in value co-creation are seen as mechanisms for service provision (Lusch and Vargo 2014; Vargo and Lusch 2008). All in all, S-D logic serves as a "meta-idea" or thinking framework at a high level of abstraction (Lusch and Vargo 2014, p. 211).

Purpose and scope. Although S-D logic is rooted in marketing, its scope is not limited to this domain. Instead, its broadened perspective is adapted in current research on digitized service innovation. The aim is to provide IS researchers a framework with underlying descriptive knowledge for conceptualizing value (co-) creation and innovation originating from digital technology from a service-based perspective (Barrett et al. 2015; Lusch and Nambisan 2015). Physical goods are not excluded but understood as mechanisms for service provisioning in line with S-D logic. The framework of digitized service innovation consists of three key elements namely value co-creation, service ecosystems, and service platforms. The service platform concept is an extension of S-D logic.

Constructs for the digitized artifact. The digitized artifact is encapsulated in the service platform concept that is defined as "a modular structure that comprises tangible and intangible components (resources) and facilitates the interaction of actors and resources (or resource bundles)" (Lusch and Nambisan 2015, p. 162). Research on digitized service innovation takes into account how actors interact with digitized artifacts instead of exclusively focusing on the physical materiality of digitized artifacts (Lusch and Nambisan 2015). In this sense, the service platform reflects the ability of a physical good to become the distribution mechanism for service provision. In line with S-D logic, it is distinguished between *operand* and *operant* resources as two resource types incorporated in the service platform. *Operand* resources are usually tangible and static resources that require some action to make them valuable. *Operant* resources, on the other hand, are usually intangible and dynamic – for instance specific capabilities or knowledge. Added value only results from the application of operant resources that may be directly transmitted or through operand resources (Vargo et al. 2008). This implies a *dual role* of the digital materiality of digitized artifacts encapsulated in the service platform construct. As operand resource, it is seen as facilitator or enabler of service innovation; as operant resource, it is seen as an initiator for service innovation (Lusch and Nambisan 2015).

Constructs for innovation. Service innovation is defined as "the rebundling of diverse resources that create novel resources that are beneficial (i.e., value experiencing) to some actors in a given context" (Lusch and Nambisan 2015, p. 160). The service platform serves as venue for service innovation, since it enables actors in the service ecosystem to seek easily or discover novel solutions to problems that may lead to innovative scalable solutions (Lusch and Nambisan 2015). The service platform concept is detached from the traditional dichotomy of service innovation and product innovation (Barrett et al. 2015; Lusch and Nambisan 2015). Instead, all innovation is understood as service innovation. Furthermore, innovation is not bound to novel technical features. In line with S-D logic's value-in-context concept, the focus moves away from the traditional perspective rooted in technological product innovation. The critical factor in this understanding is not the physical and digital materiality of the digitized artifact, but what the beneficiary can do with the digitized artifact and how it changes the beneficiary's capabilities to co-create value (Michel et al. 2008; Vargo et al. 2008).

Statements of relationship between the digitized artifact and innovation. Research on digitized service innovation focuses on the digital materiality of digitized artifacts when addressing the relationship between the artifact and innovation. Seen as both operand and operant resource, digital materiality of digitized artifacts impacts innovation in two different ways (Lusch and Nambisan 2015; Nambisan 2013). Understood as (1) *operand* resource, it enables sharing and integrating resources by supporting actors in utilizing appropriate operant resources and bundling them within and across service platforms in a given context. In this understanding, the digital materiality of digitized artifacts enables service innovation by increasing the level of resource density in the service platform when following the ideal of the layered modular architecture (Lusch and Nambisan 2015). Understood as (2) *operant* resource, the digital materiality for itself is understood as an (artificial) actor in the service ecosystem. It can independently trigger or initiate service exchange and service innovation (Lusch and Nambisan 2015). This role emphasizes how the increasing proliferation of digitized artifacts can unleash generativity and create novel opportunities for resource integration and thus service innovation (Lusch and Nambisan 2015; Nambisan 2013).

Components contingent on theory purpose. Research on digitized service innovation makes three central prescriptive statements regarding digitized artifacts and digital innovation (Lusch and Nambisan 2015). First, organizations should design their offerings as service platforms in order to enable service exchange and value co-creation. Second, a layered modular structure of the service platform enhances its level of resource density and thus facilitates service innovation. Thereby, digital materiality is in the role of an *operand* resource. Third, digital materiality should be primarily understood as an *operant* resource and thus as an initiator of service innovation within the service ecosystem (Lusch and Nambisan 2015). Hence, the framework of digitized service innovation can be classified as a theory for design and action. We note, however, that the primary purpose of the theory is to provide a thinking framework, leading to a higher level of abstraction than required in an IS design theory (Gregor 2006; Jones and Gregor 2007).

Illustrative example. Instantiating our illustrative example, the service platform as the venue for service innovation can be considered as the core element. It comprises all digital technology, i.e., the connected car, the mobile work support system for the postman, technical interfaces, and other *operand* resources. The necessary data, analytical capabilities, and competences to solve the vehicle routing problem with roaming delivery locations are conceptualized as *operant* resources. Neither telematics subcomponents and connectivity, nor the secure one-time code to open the trunk, are seen as innovations per se. Innovation results from the overall value co-creation configuration, i.e., the interaction of all actors in the ecosystem. Hence, from a S-D logic and service innovation perspective, the resulting value-in-context of the parking car as a moving packing station is the actual innovation. This innovation arises from rebundling of diverse resources in the service ecosystem consisting of the OEM, the parcel service, e-shops, and other actors. They all draw on the service platform and co-create value that is beneficial to dedicated actors (i.e., the recipient/owner of the car) in the given context. Seen as *operant* resource, digital materiality independently triggers or initiates service exchange and service innovation. The illustrative example shows that this research stream aims at providing a framework to understand how value co-creation and service innovation is enabled by digital technology by drawing on the lens of S-D logic. Material properties and prescriptive statements on digitized artifacts move into the background.

Digitized artifacts and related innovation in research on digitized product service systems

Underlying theories. Research on digitized product service systems draws on the traditional understanding of product service systems (PSS) as bundles of tangible product and intangible service components. PSS fulfill highly individual customer needs and offer value to the customer beyond the sum of its tangible and intangible components (Day 2006; Johansson et al. 2003; Oliva and Kallenberg 2003; Sharma et al. 2002; Velamuri et al. 2011). PSS describe function-, availability- or result-based offerings, instead of focusing on a onetime sales transaction (Velamuri et al. 2011).

Purpose and scope. The convergence of physical products and service offerings calls for a holistic perspective on both physical products and service offerings enabled by digital technology (Rust 2004; Fichman et al. 2014; Barrett et al. 2015). This perspective is taken by research on digitized PSS. Research in this stream focuses on the mechanisms of value creation and business models rather than the digital or physical materiality of digitized artifacts (Velamuri et al. 2011). The traditional focus of PSS on a business-to-business context in the manufacturing industry is extended to other domains and a business-to-consumer context, while the business model level remains in focus (Allmendinger and Lombreglia 2005; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014).

Constructs for the digitized artifact. In the practice-oriented work on digitized PSS, the digitized artifact is conceptualized in two different ways. The first conceptualization is based on enumerative definitions such as listings of constitutive capabilities or attributes that describe the digitized artifact (Allmendinger and Lombreglia 2005; Davis and Botkin 1994; Rijsdijk and Hultink 2009). For instance, Rijsdijk and Hultink (2009) name *autonomy, adaptability, reactivity, ability to cooperate, multi-functionality, humanlike interaction*, and *personality*. The second conceptualization emphasizes the architectural understanding of digitized PSS. The former PSS architecture is extended by a digital architecture that connects the physical product part to the intangible service offering, so providing the capability for autonomy and intelligence (Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014). Porter and Heppelmann (2015, 2014) distinguish between three core architectural components: *physical* components, *smart* components (e.g., sensors, data storage, controls, software, etc.), and *connectivity* components (e.g., ports, protocols). Since connectivity allows exchanging information between the digitized artifact and its environment, certain functions of the digitized artifact exist beyond the physical materiality in a 'product cloud' in the form of e-services (e.g., analytic functions). The interplay of digital materiality and physical materiality allows to create and realize innovative and highly integrated service offerings (Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014).

Constructs for innovation. With digitized PSS, innovation is understood in the sense of *business model innovation*. According to research on digitized PSS, innovation based on digitized artifacts can be rooted in (1) outcome-based offerings (Lerch and Gotsch 2015), (2) product-as-a-service business models (Porter and Heppelmann 2014), (3) closer, more continuous, and open-ended customer relationships (Allmendinger and Lombreglia 2005; Porter and Heppelmann 2015), and (4) the idea that capabilities of digitized PSS turn their providers into educators (e.g., with analytic functions) (Davis and Botkin 1994). In all cases, ubiquitous connectivity and ‘smartness’ of digitized PSS enable innovation on the business model level.

Statements of relationship between the digitized artifact and innovation. Both business model innovation and product innovation have been increasingly motivated by advances in digital technology (Chesbrough 2010; Zott et al. 2010). Furthermore, both are interlinked in the way that business models unlock the value potential embedded in digital technology with innovative products, and convert them into innovative market offerings (Zott et al. 2010). Turning away from digital product innovation in favor of business model innovation is the guiding principle for the relationship between the digitized artifact and innovation in the context of digitized PSS. In sum, a cycle of value improvement that eventually opens up a spectrum of new business models emerges (Porter and Heppelmann 2014).

Components contingent on theory purpose. Despite some scholarly publications such as the work of Rijsdijk and Hultink (2009), research on digitized PSS is mainly shaped by practitioner-oriented literature (Allmendinger and Lombreglia 2005; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014). Due to the mostly missing justificatory knowledge (Gregor and Jones 2007), the resulting prescriptive statements as potential core elements of theories for design and action (Gregor 2006) largely lack grounding in causal explanations.

Illustrative example. According to the understanding of digitized artifacts and related innovation in this research stream, the bundle of the connected car itself and the package-to-trunk delivery service is conceptualized as a digitized PSS. Instead of focusing on the onetime sales transaction of the car, the focus lies on the value arising from the offering beyond the sum of its tangible and intangible components, enabled by digital technology. Whereas the car by itself provides mobility, its combination with digital technology enables the package-to-drunk-delivery service. The *enumerative conceptualization* of digitized PSS would shift the focus to single aspects such as gathered location data of connected cars. As characterized by adaptability, the digitized PSS immediately adapts to changed circumstances such as a change in the location of the car. Instantiating the *architecture-oriented conceptualization*, the digitized PSS incorporates physical components (e.g., the trunk), smart components (e.g., the onetime code keyless system to open the trunk), and connectivity components (e.g., protocols that enable exchanging information between the OEM’s and parcel service’s backend systems). These connectivity components enable the package-to-trunk delivery service that for the predominant part exists outside the physical device (i.e., the car). Research on digitized PSS focuses on business outcomes of the smart combination of physical products and services enabled by digital materiality. This perspective understands the connected car as a platform for service offerings such as in-car package delivery.

Discussion

In what follows, we discuss how existing work within the individual research streams can best support researchers in future work on digitized artifacts and related innovation. Taking the perspective of scholars, we provide actionable guidance on (1) how to leverage the existing body of knowledge. We furthermore (2) discuss how ambiguities and blind spots can be addressed by further research to advance the theoretical body of knowledge on digitized artifacts and related innovation. Table 3 provides an overview on the recommendations along the two dimensions.

Table 3. Recommendations for Research on Digitized Artifacts and Related Innovation

Dimension	*Recommendation*
(1) Adequate utilization of existing concepts	R1. To conduct research on the physical and digital materiality of digitized artifacts, concepts from 'digital product innovation and digitized products' should be favored instead of concepts from 'ubiquitous and pervasive computing' research.
	R2. To conduct research on mechanisms of value (co-) creation, concepts from 'digitized service innovation' research should be favored instead of concepts from research on 'digitized product service systems'.
(2) Ambiguities and blind spots	R3. Further research is needed to untangle ambiguous aspects in the conceptualizations of digitized artifacts and related innovation within and across the research streams.
	R4. Further research is needed on the design of generative digitized artifacts and the impact of generative digitized artifacts (e.g., social, organizational, technical) on value (co-) creation.

The results section outlines four research streams that take distinct perspectives on digitized artifacts and related innovation. In their conceptualizations, the research streams emphasize different aspects of the phenomenon of digitized artifacts and related innovation, and the relationship between those two. In particular, the application of the proposed constructs and statements of relationship within the course of the illustrative example uncovers two common perspectives: (1) The physical and digital materiality of digitized artifacts (i.e., the digital technology incorporated in the connected car including data, software, and algorithms) is mostly covered by research on '*ubiquitous and* *pervasive computing'* and '*digital product innovation and digitized products'*. In contrast to this, (2) mechanisms of value (co-) creation that go beyond the physical and digital materiality of digitized artifacts are dominant in research on '*digitized service innovation'* and '*digitized product service systems'*.

Although the existence of each research stream is justified, the identified research streams within the two common perspectives, however, are characterized by different levels of maturity and adequacy. Therefore, we offer two recommendations (R1 and R2) on the adequate utilization of existing concepts.

R1. To conduct research on the physical and digital materiality of digitized artifacts, concepts from 'digital product innovation and digitized products' should be favored instead of concepts from 'ubiquitous and pervasive computing' research.

Research on (1) the physical and digital materiality of digitized artifacts should draw on concepts from the stream '*digital product innovation and digitized products'*. Rooted in decomposable systems theory, modularization, and innovation in the Schumpeterian sense, this research stream provides a sound theoretical foundation. It takes the specific material properties of digitized artifacts into account (Yoo 2010) and comprises the layered modular architecture as a generic framework for further design-oriented research. Research on *'ubiquitous and pervasive computing'*, however, omits these significant aspects of digitization. It rather focuses on the contextual factors of our phenomenon of interest as a technical one.

R2. To conduct research on mechanisms of value (co-) creation, concepts from 'digitized service innovation' research should be favored instead of concepts from research on 'digitized product service systems'.

Research on (2) mechanisms of value (co-) creation should draw on concepts from the stream *'digitized service innovation'*. This research stream is rooted in S-D logic as sound and established underlying theory with its eleven foundational premises (Vargo and Lusch 2016). It understands the digital materiality of digitized artifacts as a crucial element in service platforms. By going beyond the physical and digital materiality of digitized artifacts, research on '*digitized service innovation'* oversteps the boundaries of the artifact (Barrett et al. 2015; Lusch and Nambisan 2015). In contrast, the conceptualization of digitized artifacts in research on *'digitized product service systems'* is in its infancy and thus by nature characterized by some inconsistencies. Both, an attributive and an architectural understanding is provided. Furthermore, these distinct conceptualizations characterize the digitized artifact in a rather vague way using different terms such as ‘smart products’ (Rijsdijk and Hultink 2009), ‘smart, connected products’ (Porter and Heppelmann 2015, 2014), or ‘smart services’ (Allmendinger and Lombreglia 2005). The high level of ambiguity in research on ‘*digitized product service systems’* does not allow to feedback novel findings to the existing body of knowledge (Grover and Lyytinen 2015).

R3. Further research is needed to untangle ambiguous aspects in the conceptualizations of digitized artifacts and related innovation within and across the research streams.

Ambiguous aspects in the conceptualizations within and across the research streams hamper the advancement of a consistent theoretical body of knowledge. We identify the usage of the platform concept as a clear example for such an ambiguity. In a general sense, a platform is understood as “a building block providing essential function to a technological system – which acts as a foundation upon which other firms can develop complementary products, technologies or services” (Gawer 2009, p. 9). The platform concept is closely related to the generative capacity of digitized artifacts that is considered as being the origin for digital innovation. Our review of literature on digitized artifacts and related innovation reveals that the platform concept is used differently across the identified research streams in at least two different ways. Specifically, the platform concept is used to understand how (1) physical materiality of digitized artifacts serves as technology platform, and (2) how software platforms are used for increasing resource liquefaction.

First, research on ‘*digital product innovation and digitized products’* highlights the importance of technology platforms addressing the physical materiality of digitized artifacts. The modular layered architecture enables products to be a product and a platform at the same time (Yoo et al. 2010). Analogous, research on ‘*digitized service innovation’* sees physical products as platforms for the provision of service (Barrett et al. 2015; Lusch and Nambisan 2015). As stated in our illustrative example, the connected car itself can be seen both as a product and a platform for service and service innovation based on the layered modular architecture. Functionality that is provided by the service platform such as opening the trunk remotely can be leveraged for additional innovations beyond the in-car-delivery scenario.

Second, the platform concept is used addressing software platforms that are manifestations of the service layer and contents layer of the layered modular architecture (Yoo et al. 2012). In the illustrative example, this platform understanding focuses on the software platform that is used to collect, store, and process geospatial and other necessary data for the in-car-delivery scenario. In the research stream on *'digitized service innovation'*, service platforms are understood as modular structures consisting of tangible and intangible components that facilitate the interaction of actors and resources (Lusch and Nambisan 2015). The digital materiality incorporated in the service platform construct is a manifestation of a software platform. It is seen as a boundary resource and device to develop the relevant digital capabilities throughout the organization (Barrett et al. 2015; Ghazawneh and Henfridsson 2013). Barret et al. (2015) state that as modularity and granularity of service platforms increase, the opportunities for service innovation increase. Software platforms help to make information available to heterogeneous actors and foster generativity. Standardized interfaces and APIs are provided that allow heterogeneous actor groups unanticipated uses (Yoo 2013). In addition to the different applications of the platform concept, further ambiguity arises within the research stream on *'digitized product service systems'*. Here, the platform concept is used in both ways and is linked to platform-based business models.

R4. Further research is needed on the design of generative digitized artifacts and the impact of generative digitized artifacts (e.g., social, organizational, technical) on value (co-) creation.

Research on the design of digitized artifacts is disconnected to a large extent from research that investigates innovation based on the complementary digital materiality of digitized artifacts. The generative capacity of digitized artifacts as a novel phenomenon, however, demonstrates the link between the generative design of digitized artifacts and resulting contextual affordances. Considering how the generative capacity is addressed in existing research, two blind spots become obvious.

Lyytinen and Yoo (2002) call for research dealing with design, use, and adoption of ubiquitous and pervasive computing environments. Due to the generative capacity of digitized artifacts, however, they have to be designed without knowing the "whole design" (Yoo 2013, p. 230). Their generative nature makes it difficult to provide concrete guidance for designing digitized artifacts. Thus, the development of digitized artifacts has to be performed "distributed across heterogeneous disciplines and communities" (Yoo et al. 2012, p. 730). This calls for a deeper understanding and design knowledge on digitized artifacts across the boundaries of a single discipline.

Research on digitized service innovation so far focuses on investigating the configuration of a service platform and value co-creation within a service ecosystem instead of the evolution of innovation based on digitized artifacts. However, it is unclear, how actors in service ecosystems have to cope with co-creating value when taking into account digitized artifacts. This aspect might particularly be important in an industrial context. Hence, scholars should focus on elicitation of design principles of digitized artifacts taking into account the specific requirements of dedicated use contexts. The experiential computing framework (Yoo 2010) might serve as foundational knowledge for building up sound prescriptive knowledge on the proper design of digitized artifacts.

The generative nature of digitized artifacts re-shapes the industrial landscape (Yoo 2013). Product-centric organizations are outshined by technology-savvy organizations that focus on transforming entire industries by leveraging digital technology. Hence, traditional theories that provide guidance for strategic management of modular innovation can no longer offer effective guidance in a world of generative digitized artifacts (Henderson and Clark 1990; Yoo 2013). First attempts exist that focus on affordances of digitized artifacts in the context of industrial manufacturing (Herterich et al. 2016) and how digitized artifacts transform organizations (Hylving and Schultze 2013; Hildebrandt et al. 2015; Piccinini et al. 2015). Further research should provide prescriptions such as principles of form and function that provide guidelines for building digitized artifacts and methods for implementing digitized artifacts from an organizational perspective. Besides, the interdisciplinary and boundary-spanning design process is largely omitted in the current body of knowledge. Interdisciplinary approaches such as design thinking are promising tools to design digitized artifacts and related innovation effectively (Barrett et al. 2015).

Conclusion

The work at hand provides an in-depth analysis of scholarly knowledge addressing the real-world-phenomenon of physical artifacts getting augmented with digital technology (i.e., digitized artifacts). We develop and adapt an analysis framework geared towards the structural nature of theories in IS to understand how digitized artifacts and related innovation are conceptualized in existing literature. We identify four research streams that fundamentally differ in their conceptualizations. We discuss how these conceptualizations contribute to a better understanding of digitized artifacts and related innovation. By means of an illustrative example, we apply the results of our analysis to a real-world case to sharpen the understanding of existing concepts and theories. We illustrate how digitized artifacts, innovation, and the relationship between those two is understood differently in different streams of research. Our findings advance the theoretical body of knowledge by "showing how competing theories […] [that] explain an important phenomenon can be very influential" (Webster and Watson 2002, p. xix).

This paper aims to help scholars to conduct research on digitized artifacts and digital innovation in a material world. Based on four actionable recommendations, we (1) provide guidance on when to use the existing conceptualizations and (2) reveal ambiguities and blind spots in existing research that might have prevented advancing theory and should be addressed in future research. Yet, this study is beset with multiple limitations that we would like to address in the following. First, due to the width of the topic, we do not claim to provide an exhaustive overview of literature with this study. Second, as any literature review, this work faces limitations with regard to the literature selection process. By using a broad search string and going beyond the IS discipline, we minimized the risk of missing out relevant publications. Despite the limitations, we believe that our work serves as a necessary foundation for building middle-range explanations and designing digitized artifacts and related innovation in a comprehensive way.

Appendix

Table 4. Detailed Overview of the Systematic Selection and Review of Literature

Stage	*Applied exclusion criterion*	*Added or removed publications*	*Count*	*Total*
Keyword search	n.a.	Initial set obtained from keyword search: 820 publications added from IS outlets, 935 publications added from Innovation Management outlets	1755	1755
Initial screening	Screening of titles and abstracts by two researchers individually	Publications excluded based on screening of titles and abstracts; publications added based on forward and backward search	1683	72
Analysis and identification of research streams	Formal criteria (research-in-progress publications, interviews, summaries of panel discussions, short publications, commentaries)	Publications removed that did not meet formal criteria	20	52
	Focus on organizational perspective	Removed: (Amable and Palombarini 1998; Granstrand 1998; Leiponen and Drejer 2007; Loebbecke and Picot 2015; Ogilvie 2015; Parida et al. 2015; Sambamurthy and Zmud 2000; Setia et al. 2013)	8	44
	Focus on digital platforms or digital infrastructure	Removed: (Henfridsson and Bygstad 2013; Kuebel and Zarnekow 2015; Ozer and Anderson 2015; Tiwana et al. 2010; Xinlin Tang et al. 2011)	5	39
	Focus on processes or production	Removed: (Marion et al. 2015; Neff et al. 2014)	2	37
	Focus on purely digital artifacts (artifacts without physical materiality)	Removed: (Featherman et al. 2006; Lyytinen et al. 1998; Newell and Marabelli 2015; Newell 2015; Stein et al. 2013; Thong et al. 2011)	6	31
	Lack of explicit or implicit statements with regard to the dimensions of the analysis framework	Removed: (van den Ende and Kemp 1999; Ferguson 1990; Green and Hull 1999; Lee et al. 2013; Parmar et al. 2014; Peine 2008; Pramatari and Theotokis 2009; Srinivasan et al. 2007)	8	23
Final set of 23 publications that conceptualize digitized artifacts and related innovation				

Table 5. Overview of Referenced Sources in the Identified Research Streams along the Dimensions of our Analysis Framework

Dimension	*Characteristic*	*Ubiquitous and pervasive computing*	*Digital product innovation and digitized products*	*Digitized service innovation*	*Digitized product service systems*
Underlying theories		(Porter 1985), *referenced in* (Jonsson et al. 2008)	(Baldwin and Clark 2000; Majchrzak and Markus 2013; Schilling 2000; Simon 1996; Zittrain 2006), *referenced in* (Yoo et al. 2012, 2010, 2010)	(Lusch and Vargo 2014; Lusch et al. 2010; Vargo and Lusch 2004, 2016, 2008; Vargo et al. 2008), *referenced in* (Barrett et al. 2015; Lusch and Nambisan 2015)	(Day 2006; Johansson et al. 2003; Oliva and Kallenberg 2003; Sharma et al. 2002; Velamuri et al. 2011), *referenced in* (Lerch and Gotsch 2015)
Purpose and scope		(Kourouthanassis et al. 2010; Lyytinen and Yoo 2002)	(Yoo 2010, 2013, Yoo et al. 2012, 2010, 2010)	(Barrett et al. 2015; Lusch and Nambisan 2015)	(Allmendinger and Lombreglia 2005; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014)
Constructs	Digitized artifact	(Dey 2001; Kourouthanassis et al. 2010)	(Yoo et al. 2010; Yoo 2013)	(Lusch and Nambisan 2015)	(Allmendinger and Lombreglia 2005; Davis and Botkin 1994; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014; Rijsdijk and Hultink 2009)
	Innovation	(Jonsson et al. 2008; Kourouthanassis et al. 2010; Watson et al. 2011)	(Fichman et al. 2014; Hildebrandt et al. 2015; Yoo et al. 2012, 2010)	(Barrett et al. 2015; Lusch and Nambisan 2015)	(Allmendinger and Lombreglia 2005; Davis and Botkin 1994; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014)
Statements of relationship between the digitized artifact and innovation		n.a.	(Henfridsson et al. 2014; Hildebrandt et al. 2015; Lyytinen et al. 2015; Piccinini et al. 2015; Yoo et al. 2012, 2010; Yoo 2013)	(Lusch and Nambisan 2015; Nambisan 2013)	(Porter and Heppelmann 2014)
Components contingent on theory purpose		n.a.	(Henfridsson et al. 2014; Hylving and Schultze 2013; Hylving et al. 2012; Lyytinen et al. 2015; Yoo et al. 2012; Yoo 2013)	(Lusch and Nambisan 2015)	(Allmendinger and Lombreglia 2005; Lerch and Gotsch 2015; Porter and Heppelmann 2015, 2014; Rijsdijk and Hultink 2009)

References

Allmendinger, G., and Lombreglia, R. 2005. "Four Strategies for the Age of Smart Services," *Harvard Business Review* (83:10), pp. 131-145.

Amable, B., and Palombarini, S. 1998. "Technical Change and Incorporated R & D in the Service Sector," *Research Policy* (27:7), pp. 655-675.

Anderson, P., and Tushman, M. L. 1990. "Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change," *Administrative Science Quarterly* (35:4), pp. 604–633.

Baldwin, C. Y., and Clark, K. B. 2000. *Design Rules: The Power of Modularity*, Cambridge, MA: MIT Press.

Barrett, M., Davidson, E., Prabhu, J., and Vargo, S. L. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Quarterly* (39:1), pp. 135–154.

Belanger, F., and Crossler, R. 2011. "Privacy in the Digital Age: A Review of Information Privacy Research in Information Systems," *MIS Quarterly* (35:4), pp. 1017–1041.

Chesbrough, H. 2010. "Business Model Innovation: Opportunities and Barriers," *Long Range Planning* (43:2/3), pp. 354–363.

Clark, K. B. 1985. "The Interaction of Design Hierarchies and Market Concepts in Technological Evolution," *Research Policy* (14:5), pp. 235–251.

Davis, S., and Botkin, J. 1994. "The Coming of Knowledge-Based Business," *Harvard Business Review* (72:5), pp. 165–170.

Day, G. 2006. "Achieving Advantage with a Service-Dominant Logic," in *The Service-Dominant Logic of Marketing: Dialog, Debate, and Directions.*, R.F. Lusch and S.L. Vargo (eds.), New York: Routledge, pp. 1–90.

Dey, A. K. 2001. "Understanding and Using Context," *Personal Ubiquitous Computing.* (5:1), pp. 4–7.

Van den Ende, J., and Kemp, R. 1999. "Technological Transformations in History: How the Computer Regime Grew Out of Existing Computing Regimes," *Research Policy* (28:8), pp. 833–851.

Ewing, J. 2015. "Audi to Test Plan to Deliver Amazon Packages to Drivers' Trunks," in *The New York Times* from 22nd April 2015.

Featherman, M. S., Valacich, J. S., and Wells, J. D. 2006. “Is that authentic or artificial? Understanding consumer perceptions of risk in e-service encounters,” *Information Systems Journal* (16:2), pp. 107–134.

Ferguson, C. H. 1990. “Computers and the Coming of the U.s. Keiretsu,” *Harvard Business Review* (68:4), pp. 55–70.

Fichman, R. G., Dos Santos, B. L., and Zheng, Z. E. 2014. “Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum,” *MIS Quarterly* (38:2), pp. 329–353.

Gawer, A. 2014. “Bridging Differing Perspectives on Technological Platforms: Toward an Integrative Framework,” *Research Policy* (43:7), pp. 1239–1249.

Gawer, A. 2009. *Platforms, Markets and Innovation*, Northampton, MA: Edward Elgar Publishing.

Ghazawneh, A., and Henfridsson, O. 2013. “Balancing Platform Control and External Contribution in Third-Party Development: The Boundary Resources Model,” *Information Systems Journal* (23:2), pp. 173–192.

Granstrand, O. 1998. “Towards a Theory of the Technology-Based Firm,” *Research Policy* (27:5), pp. 465–489.

Green, K., and Hull, R. 1999. “The Construction of the Techno-Economic: Networks vs. Paradigms,” *Research Policy* (28:7), pp. 777-792.

Gregor, S., and Jones, D. 2007. “The Anatomy of a Design Theory,” *Journal of the Association for Information Systems* (8:5), pp. 312–335.

Gregor, S. 2006. “The Nature of Theory in Information Systems,” *MIS Quarterly* (30:3), pp. 611–642.

Grover, V., and Lyytinen, K. 2015. “New State of Play in Information Systems Research: The Push to the Edges,” *MIS Quarterly* (39:2), pp. 271-A5.

Henderson, R. M., and Clark, K. B. 1990. “Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms,” *Administrative Science Quarterly* (35:1), pp. 9–30.

Henfridsson, O., and Bygstad, B. 2013. “The Generative Mechanisms of Digital Infrastructure Evolution,” *MIS Quarterly* (37:3), pp. 907-A5.

Henfridsson, O., Mathiassen, L., and Svahn, F. 2014. "Managing Technological Change in the Digital Age: The Role of Architectural Frames," *Journal of Information Technology* (29:1), pp. 27–43.

Herterich, M., Eck, A., and Uebernickel, F. 2016. "Exploring How Digitized Products Enable Industrial Service Innovation - An Affordance Perspective," in *Proceedings of the 24rd European Conference on Information Systems (ECIS)*, Istanbul.

Hildebrandt, B., Hanelt, A., Firk, S., and Kolbe, L. 2015. "Entering the Digital Era – The Impact of Digital Technology-related M&As on Business Model Innovations of Automobile OEMs," in *Proceedings of the 36th International Conference on Information System*, Fort Worth, TX.

Hylving, L., Henfridsson, O., and Selander, L. 2012. "The Role of Dominant Design in a Product Developing Firm's Digital Innovation," *Journal of Information Technology Theory and Application (JITTA)* (13:2), pp. 5–21.

Hylving, L., and Schultze, U. 2013. "Evolving the Modular Layered Architecture in Digital Innovation: The Case of the Car's Instrument Cluster," in *Proceedings of the 34th International Conference on Information Systems (ICIS)*, Milan, Italy.

Johansson, J. E., Krishnamurthy, C., and Schlissberg, H. E. 2003. "Solving the Solutions Problem," *McKinsey Quarterly* (3), pp. 116–125.

Jones, D., and Gregor, S. 2007. "The Anatomy of a Design Theory," *Journal of the Association for Information Systems* (8:5), pp. 312–335.

Jonsson, K., Westergren, U. H., and Holmström, J. 2008. "Technologies for Value Creation: An Exploration of Remote Diagnostics Systems in the Manufacturing Industry," *Information Systems Journal* (18:3), pp. 227–245.

Kallinikos, J., Aaltonen, A., and Marton, A. 2013. "The Ambivalent Ontology of Digital Artifacts," *MIS Quarterly* (37:2), pp. 357–370.

Kourouthanassis, P. E., Giaglis, G. M., and Karaiskos, D. C. 2010. "Delineating 'Pervasiveness' in Pervasive Information Systems: A Taxonomical Framework and Design Implications," *Journal of Information Technology* (25:3), pp. 273–287.

Kuebel, H., and Zarnekow, R. 2015. "Exploring Platform Adoption in the Smart Home Case," *Proceedings of the 36th International Conference on Information Systems (ICIS)*, Fort Worth, TX.

Lansiti, M., and Lakhani, K. R. 2014. "Digital Ubiquity: How Connections, Sensors, and Data Are Revolutionizing Business," *Harvard Business Review* (92:11), pp. 90–99.

Lee, S., Lee, J.-H., and Garrett, T. C. 2013. "A Study of the Attitude Toward Convergent Products: A Focus on the Consumer Perception of Functionalities A Study of the Attitude toward Convergent Products: A Focus on the Consumer Perception of Functionalities," *Journal of Product Innovation Management* (30:1), pp. 123–135.

Leiponen, A., and Drejer, I. 2007. "What Exactly are Technological Regimes? Intra-industry Heterogeneity in the Organization of Innovation Activities," *Research Policy* (36:8), pp. 1221–1238.

Lerch, C., and Gotsch, M. 2015. "Digitalized Product-Service Systems in Manufacturing Firms," *Research Technology Management* (58:5), pp. 45–52.

Linton, J. D., and Thongpapanl, N. (Tek) 2004. "Perspective: Ranking the Technology Innovation Management Journals," *Journal of Product Innovation Management* (21:2), pp. 123–139.

Loebbecke, C., and Picot, A. 2015. "Reflections on societal and business model transformation arising from digitization and big data analytics: A research agenda," *Journal of Strategic Information Systems* (24:3), pp. 149–157.

Lowry, P. B., Moody, G. D., Gaskin, J., Galletta, D. F., Humpherys, S. L., Barlow, J. B., et al. 2013. "Evaluating Journal Quality and the Association for Information Systems Senior Scholars' Journal Basket Via Bibliometric Measures: Do Expert Journal Assessments Add Value?," *MIS Quarterly* (37:4), pp. 993–1012.

Lusch, R. F., and Nambisan, S. 2015. "Service Innovation: A Service-Dominant Logic Perspective," *MIS Quarterly* (39:1), pp. 155–175.

Lusch, R. F., Vargo, S. L., and Tanniru, M. 2010. "Service, Value Networks and Learning," *Journal of the Academy of Marketing Science* (38:1), pp. 19–31.

Lusch, R. F., and Vargo, S. L. 2014. *Service-Dominant Logic: Premises, Perspectives, Possibilities*, New York: Cambridge University Press.

Lyytinen, K., and Rose, G. M. 2003. "The Disruptive Nature of Information Technology Innovations: The Case of Internet Computing in Systems Development Organizations," *MIS Quarterly* (27:4), pp. 557–595.

Lyytinen, K., Rose, G., and Welke, R. 1998. "The Brave New World of Development in the Internetwork Computing Architecture (InterNCA): or How Distributed Computing Platforms will Change Systems Development," *Information Systems Journal* (8:3), pp. 241–253.

Lyytinen, K., Yoo, Y., and Boland, R. J. 2015. "Digital Product Innovation within Four Classes of Innovation Networks: Digital Product Innovation," *Information Systems Journal* (26:1), pp. 47–75.

Lyytinen, K., and Yoo, Y. 2002. "Research Commentary: The Next Wave of Nomadic Computing," *Information Systems Research* (13:4), pp. 377–388.

Lyytinen, K., and Yoo, Y. 2002. "Ubiquitous Computing," *Communications of the ACM* (45:12), pp. 63–65.

Majchrzak, A., and Markus, M. L. 2013. "Technology Affordances and Constraints in Management Information Systems (MIS)," in *Encyclopedia of Management Theory*, E. Kessler (ed.), Thousand Oaks, CA: Sage Publications, pp. 832–836.

Marion, T. J., Meyer, M. H., and Barczak, G. 2015. "The Influence of Digital Design and IT on Modular Product Architecture," *Journal of Product Innovation Management* (32:1), pp. 98–110.

Markus, M. L., and Silver, M. S. 2008. "A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole's Concepts of Structural Features and Spirit," *Journal of the Association for Information Systems* (9:10–11), pp. 609–632.

Michel, S., Brown, S. W., and Gallan, A. S. 2008. "An Expanded and Strategic View of Discontinuous Innovations: Deploying a Service-Dominant Logic," *Journal of the Academy of Marketing Science* (36:1), pp. 54–66.

Nambisan, S. 2013. "Information Technology and Product/Service Innovation: A Brief Assessment and Some Suggestions for Future Research," *Journal of the Association for Information Systems* (14), pp. 215–226.

Neff, A. A., Hamel, F., Herz, T. P., Uebernickel, F., Brenner, W., and vom Brocke, J. 2014. "Developing a Maturity Model for Service Systems in Heavy Equipment Manufacturing Enterprises," *Information & Management* (51:7), pp. 895–911.

Newell, S., and Marabelli, M. 2015. "Strategic Opportunities (and Challenges) of Algorithmic Decision-Making: A Call for Action on the Long-term Societal Effects of 'Datification,'" *Journal of Strategic Information Systems* (24:1), pp. 3–14.

Newell, S. 2015. “Managing Knowledge and Managing Knowledge Work: What We Know and What the Future Holds,” *Journal of Information Technology (Palgrave Macmillan)* (30:1), pp. 1–17.

Ogilvie, T. 2015. “How to Thrive in the Era of Collaborative Services Entrepreneurship,” *Research Technology Management* (58:5), pp. 24–33.

Oliva, R., and Kallenberg, R. 2003. “Managing the Transition from Products to Services,” *International Journal of Service Industry Management* (14:2), pp. 160–172.

Ozer, G., and Anderson, E. 2015. “Innovation and Breaching Strategies in Multi-sided Platform markets: Insights from a Simulation Study,” *Proceedings of the 36th International Conference on Information Systems (ICIS)*, Fort Worth, TX.

Parida, V., Sjödin, D. R., Lenka, S., and Wincent, J. 2015. “Developing Global Service Innovation Capabilities,” *Research Technology Management* (58:5), pp. 35–44.

Parmar, R., Mackenzie, I., Cohn, D., and Gann, D. 2014. “The New Patterns of Innovation,” *Harvard Business Review* (92:1/2), pp. 86–95.

Peine, A. 2008. “Technological Paradigms and Complex Technical Systems - The Case of Smart Homes,” *Research Policy* (37:3), pp. 508–529.

Piccinini, E., Hanelt, A., Gregory, R., and Kolbe, L. 2015. “Transforming Industrial Business: The Impact of Digital Transformation on Automotive Organizations,” in *Proceedings of the 36th International Conference on Information System*, Fort Worth, TX.

Porter, M. E., and Heppelmann, J. E. 2015. “How Smart, Connected Products Are Transforming Companies,” *Harvard Business Review* (93:10), pp. 96–114.

Porter, M. E., and Heppelmann, J. E. 2014. “How Smart, Connected Products Are Transforming Competition,” *Harvard Business Review* (92:11), pp. 64–88.

Porter, M. E. 1985. *Competitive Advantage: Creating and Sustaining Superior Performance*, New York: Simon & Schuster.

Pramatari, K., and Theotokis, A. 2009. “Consumer Acceptance of RFID-enabled Services: A Model of Multiple Attitudes, Perceived System Characteristics and Individual Traits,” *European Journal of Information Systems* (18:6), pp. 541–552.

Rijsdijk, S. A., and Hultink, E. J. 2009. “How Today’s Consumers Perceive Tomorrow’s Smart Products,” *Journal of Product Innovation Management* (26:1), pp. 24–42.

Rowe, F. 2014. “What Literature Review Is Not: Diversity, Boundaries and Recommendations,” *European Journal of Information Systems* (23:3), pp. 241–255.

Rust, R. 2004. “If Everything Is Service, Why Is this Happening Now, and What Difference Does it Make?,” *Journal of Marketing* (68:1), pp. 23–24.

Sambamurthy, V., and Zmud, R. W. 2000. “The Organizing Logic for an Enterprise’s IT Activities in the Digital Era - A Prognosis of Practice and a Call for Research,” *Information Systems Research* (11:2), p. 105.

Schilling, M. A. 2000. “Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity,” *Academy of Management Review* (25:2), pp. 312–334.

Schumpeter, J. A. 1934. *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*, London, England: Transaction publishers.

Setia, P., Venkatesh, V., and Joglekar, S. 2013. “Leveraging Digital Technologies: How Information Quality Leads to Localized Capabilities and Customer Service Performance,” *MIS Quarterly* (37:2), pp. 565-A4.

Sharma, D., Lucier, C., and Molloy, R. 2002. “From Solutions to Symbiosis: Blending with Your Customers,” *Strategy and Business* (27), pp. 38–43.

Shepherd, D. A., and Sutcliffe, K. M. 2011. “Inductive Top-Down Theorizing: A Source of New Theories of Organization,” *Academy of Management Review* (36:2), pp. 361–380.

Simon, H. A. 1996. *The Sciences of the Artificial*, Cambridge, MA: MIT Press.

Srinivasan, R., Haunschild, P., and Grewal, R. 2007. “Vicarious Learning in New Product Introductions in the Early Years of a Converging Market,” *Management Science* (53:1), pp. 16–28.

Stein, M.-K., Newell, S., Galliers, R., and Wagner, E. 2013. “Classification Systems, their Digitization and Consequences for Data-Driven Decision Making: Understanding Representational Quality,” *ICIS 2013 Proceedings*.

Thong, J. Y. L., Venkatesh, V., Xu, X., Hong, S.-J., and Tam, K. Y. 2011. “Consumer Acceptance of Personal Information and Communication Technology Services,” *IEEE Transactions on Engineering Management* (58:4), pp. 613–625.

Tilson, D., Lyytinen, K., and Sørensen, C. 2010. “Digital Infrastructures: The Missing IS Research Agenda,” *Information Systems Research* (21:4), pp. 748–759.

Tiwana, A., Konsynski, B., and Bush, A. A. 2010. "Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics," *Information Systems Research* (21:4), pp. 675–687.

Van der Meulen, R. 2015. "Gartner Says 6.4 Billion Connected 'Things' Will Be in Use in 2016, Up 30 Percent From 2015," in *Gartner Symposium/ITxpo 2015*, Barcelona, Spain.

Vargo, S. L., and Lusch, R. F. 2004. "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing* (68:1), pp. 1–17.

Vargo, S. L., and Lusch, R. F. 2016. "Institutions and Axioms: An Extension and Update of Service-dominant Logic," *Journal of the Academy of Marketing Science* (44:1), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2008. "Service-Dominant Logic: Continuing the Evolution," *Journal of the Academy of Marketing Science* (36:1), pp. 1–10.

Vargo, S. L., Maglio, P. P., and Akaka, M. A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145–152.

Velamuri, V. K., Neyer, A.-K., and Möslein, K. M. 2011. "Hybrid Value Creation: A Systematic Review of an Evolving Research Area," *Journal für Betriebswirtschaft* (61:1), pp. 3–35.

Volkoff, O., and Strong, D. M. 2013. "Critical Realism and Affordances: Theorizing IT-Associated Organizational Change Processes," *MIS Quarterly* (37:3), pp. 819–834.

Watson, R. T., Boudreau, M.-C., Chen, A. J., and Sepúlveda, H. H. 2011. "Green Projects: An Information Drives Analysis of four Cases," *Journal of Strategic Information Systems* (20:1), pp. 55–62.

Webster, J., and Watson, R. T. 2002. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," *MIS Quarterly* (26:2), pp. xiii–xxiii.

Xinlin, Tang, Rai, A., and Wareham, J. 2011. "Bridging and Bonding in Exchange Networks: A Structural Embeddedness Perspective of B2B Digital Intermediation," *IEEE Transactions on Engineering Management* (58:1), pp. 4–20.

Yoo, Y., Boland, R. J., Lyytinen, K., and Majchrzak, A. 2012. "Organizing for Innovation in the Digitized World," *Organization Science* (23:5), pp. 1398–1408.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724–735.

Yoo, Y. 2010. "Computing in Everyday Life: A Call for Research on Experiential Computing," *MIS Quarterly* (34:2), pp. 213–231.

Yoo, Y. 2013. "The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research?," *Journal of the Association for Information Systems* (14:5), pp. 227–236.

Zittrain, J. 2006. *The Future of the Internet and How to Stop it*, New Haven, CT: Yale University Press.

Zott, C., Amit, R., and Massa, L. 2010. "The Business Model – Theoretical Roots, Recent Development, and Future Research," *Journal of Management* (37:4), pp. 1019–1042.

B – **Article II**

Herterich, M.M. (2017). “On the Design of Digitized Industrial Products as Key Resources of Service Platforms for Industrial Service Innovation. In: *Lecture Notes in Computer Science (LNCS), Proceedings of the 12th International Conference on Design Science Research in Information Systems and Technology (DESRIST)*. Karlsruhe, Germany.

On the Design of Digitized Industrial Products as Key Resources of Service Platforms for Industrial Service Innovation

Matthias M. Herterich [a, b]

[a] University of St.Gallen
9000 St.Gallen, Switzerland
matthias.herterich@unisg.ch

[b] Center for Design Research (CDR)
Stanford University, Stanford, USA
matthias.herterich@stanford.edu

Abstract

The pervasive infiltration of digital technology into physical products fundamentally changes the requirements regarding the design of physical products and their potential for service innovation. To effectively leverage the generative capacity of digitized industrial products in future smart service offerings, proper design decisions must be made when designing today's products. The purpose of this paper is to report on a 2.5-year action design research project with an industrial forklift manufacturer, a software company, and an IoT consultancy. I elicit meta-requirements of digitized products arising from the industrial service business and derive design principles for digitized industrial products. This work empowers researchers to better understand the importance of generative product design to enable opportunities to innovative services. For managers, this work provides a blueprint for the design of digitized industrial products and raises awareness for generative product design in the digital age.

Keywords: Digital product, Service innovation, Generativity, Manufacturing industry, Servitization in manufacturing, Design principles, Action design research.

Introduction

The pervasive infiltration of digital technology into products that so far have been solely physical, fundamentally changes the way how product-centric organizations co-create value (Barrett et al. 2015; Lakhani and Iansiti 2014; Lusch and Nambisan 2015; Yoo et al. 2010). Innovation is no longer bound to physical product design and no longer follows the traditional goods-dominant logic (Sawhney et al. 2006). Instead, tangible products are increasingly understood as distribution mechanisms (Vargo et al. 2008) and endpoints for service to co-create value with customers as actors in service ecosystems (Lusch and Nambisan 2015). As a result, original equipment manufacturers (OEMs) increasingly shift from selling products to selling integrated product-service offerings (Lightfoot et al. 2013; Neely 2008; Ulaga and Reinartz 2011). Specifically, industrial OEMs have recognized the importance of the service business among the long lifecycles of their products (Blinn et al. 2008). High requirements in terms of product reliability and uptime make product operators pay for services offered by OEMs to ensure stress-free and failure-free operations. The term servitization in manufacturing was coined to describe this trend (Lightfoot et al. 2013; Ulaga and Reinartz 2011). Thus, product design and digital technology incorporated in today's industrial products is one of the key competitive advantages to offer differentiating smart services tomorrow (Herterich et al. 2016; Maglio 2015; Medina-Borja 2015). The structure and architecture of digitized products affect how they behave, function, and evolve over time (Tiwana 2014). Because of the added digital materiality of products, product design goes beyond the pure physical representation (Tilson et al. 2010; Yoo et al. 2010). Traditionally rooted in mechanical engineering, OEMs face the challenge to build up adequate expertise as well as digitized products and digital infrastructure as platforms for service innovation. They therefore struggle in designing digitized industrial products that are characterized by a high generative capacity, which means that they offer the potential to be leveraged in a multitude of unanticipated and innovative industrial services (Yoo 2013).

The IS community picks up this trend and calls for design-oriented research on the generative design of digitized products (Herterich and Mikusz 2016; Porter and Heppelmann 2015, 2014; Yoo 2010) and their innovative uses in smart service systems (Barrett et al. 2015; Böhmann et al. 2014; Herterich et al. 2016, 2016; Lusch and Nambisan 2015). So far, no research on the actual design and implementation of digitized products that are used as resources for service innovation exist. Therefore, the objective of this paper is to close this gap by (1) identifying meta-requirements of digitized products that arise in the context of the industrial service business and (2) formulating design principles for digitized products as resources in digitized service systems. Accordingly, the following two research questions are formulated:

(1) *What are meta-requirements of digitized industrial products in the industrial service business?*
(2) *How should digitized industrial products be designed to address these requirements?*

The remainder of this paper is structured as follows. In section two, I provide the relevant theoretical foundation and introduce relevant terms and concepts for this work. Section three outlines the research approach. In section four, the identified meta-requirements and the design are presented. Section five reports on the generalizable design principles. The paper closes with discussing and summarizing the results and a conclusion.

Theoretical foundation and related work

Existing research on digitized products is highly interdisciplinary and scattered across various disciplines. Among scholars, different conceptualizations of the emerging digital and physical materiality (Leonardi and Barley 2008) of digitized products exist. As research on this topic is still at its infancy, Herterich and Mikusz (2016) identify two dominant research streams with major scientific impact, namely (1) 'digital product innovation and digitized products' (Yoo 2010; Yoo et al. 2012, 2010) and (2) 'digitized service innovation' (Barrett et al. 2015; Lusch and Nambisan 2015; Lusch and Vargo 2014; Vargo and Lusch 2016).

First, focusing on digital product innovation and digitized products, the concept of 'digital product innovation' can be considered as the most comprehensive and scholarly recognized vocabulary for describing the phenomenon (2010; 2012). Yoo et al. (2010) define digital product innovation as 'the carrying out of new combinations of digital and physical components to produce novel products' (Yoo et al. 2010, p. 725). The layered modular architecture is considered as a framework for describing the design of digitized products (Yoo et al. 2010). The paper at hand draws on this conceptualization and understands digitized products consisting of four layers. The *device layer* deals with physical machinery properties and logical issues at operating system level. The *network layer* focuses on the physical aspects of data transmission. The *service layer* addresses application functionality enabling actions such as create, manipulate, store, and consume contents. The *contents layer* finally addresses the digital content related to the digitized product. Unlike traditional physical products, digitized products that follow the principles of the modular layered architecture hold a high generative capacity as potential foundation for innovative services (Yoo 2013; Zittrain 2006, 2006). The term generativity refers to “a system’s overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences” (Zittrain 2006, p. 1980). The concept recently got attention in the context of digital innovation research (Eck et al. 2015). Eck and Uebernickel (Eck and Uebernickel 2016) identify two perspectives on generativity: (1) generativity as consequence of system design and (2) generativity as consequence of system evolution. Existing work on product innovation largely omits this generative capacity although acknowledging the related explorative and iterative innovation processes (Eisenhardt and Tabrizi 1995; Henderson and Clark 1990) and recognizing the importance of generative for innovation (Piccinini et al. 2015; Woodard and Clemons 2014). For this paper, I draw on the first perspective and focus on investigating the generative design of digitized industrial products and the consequent capacity of generating a multitude of surprising uses of within the given context of the industrial service business.

Second, research on service systems and service innovation goes beyond the digital and physical materiality and focuses on leveraging the generative capacity of digitized products in smart service systems (Barrett et al. 2015; Böhmann et al. 2014; Lusch and Nambisan 2015). Service innovation literature understands digitized products as service platforms consisting of tangible and intangible components (resources) (Lusch and Nambisan 2015). Barrett et al. (2015) recognize the increasing focus on service in different industries and argue that pervasive digitization and the generative capacity of digital technology afford dramatic new opportunities for service innovation. Particularly the manufacturing industry is dominantly focused on physical products and the traditional principle of value in exchange (Ulaga and Reinartz 2011; Vargo et al. 2008). Thus, the generative capacity of digitized artifacts allows unanticipated potential for service innovation (Zittrain 2006). As an example, imagine a manufacturer of forklifts. Instead of selling forklift trucks as one-time transactions and additionally offering traditional ad hoc maintenance and repair services, digitized industrial products afford the OEM to implement service-oriented pay-per-use business models and draw on the concept of value-in-use (Vargo et al. 2008) to eventually outpace traditional goods-dominant competitors.

In between these two fields of research, the need for design knowledge on digitized products (Hylving et al. 2012), the necessary information architecture (Dreyer et al.

2017), and digital service platforms (Göbel and Cronholm 2016) arises. The generative nature of digitized products, however, makes it challenging to design these products, because requirements originate from unanticipated smart industrial services and cannot be defined yet. So far to the best of my knowledge, no research exists that focuses on the design of digitized products considering their generative nature. Therefore, the aim of this paper is to elicit design principles as guidelines for generative digitized industrial products that form platforms for industrial service innovation in the digital age.

Research approach

Within this article, I report on the elicitation of meta-requirements (MRs) and elaboration of design principles (DPs) of digitized industrial products as service platforms for industrial service innovation. The interdisciplinary nature of this research between digitized products (Lyytinen et al. 2015) and service innovation (Barrett et al. 2015) demands for authentic and concurrent evaluation activities (Fichman et al. 2014; Yoo 2010). Action design research (ADR) is identified as an adequate emerging methodology with the goal to obtain relevant results by means of a rigorous yet pragmatic approach (Sein et al. 2011). I chose ADR over other design-oriented research approaches since they relegate evaluation to a subsequent project phase exclusively (Sein et al. 2011). By drawing on the existing body of knowledge, ADR aims to develop prescriptive design knowledge by building and evaluating innovative IT artifacts. It furthermore aims to develop innovative and useful solutions for classes of problems that are relevant for practice solve an identified class of problems (Hevner et al. 2004; March and Smith 1995; Sein et al. 2011). Therefore, a 2.5-year lasting ADR project was set up following the guidelines of Sein et al. (2011).

Following the ADR methodology, initially the problem is formulated by eliciting MRs. MRs are addressed by solving one specific problem instance and come up with a concrete solution design. This approach is in line with Böhmann et al. (Böhmann et al. 2014), who propose that research related with interdisciplinary service systems engineering should draw on a real-world problem instance. The built solution is refined in an authentic and concurrent manner within a reflection and learning stage. Finally, learnings are formalized as generic DPs. DPs are the most common form of prescriptive design knowledge and describe how a system or product should be built in order to fulfill MRs as identified and theorized attributes of an aspired system or product (Hevner et al. 2004; Walls et al. 1992). Figure 1 on the following page provides an illustrative overview of the ADR project.

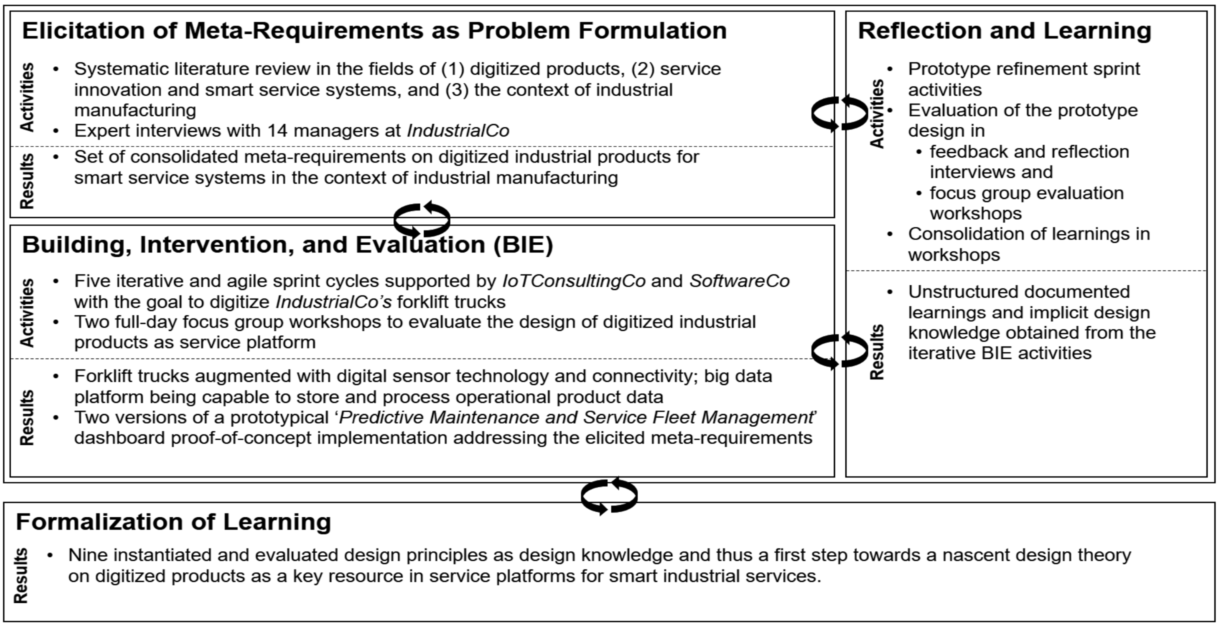


Figure 1. Overview of ADR stages with key activities and results adapted from Sein et al. (Sein et al. 2011)

Three interdisciplinary industrial partners were selected for the ADR project based on their willingness to gain practical experiences on the augmentation of industrial products with digital technology with the goal to offer innovative services. Considering the interdisciplinary nature of this project, *IndustrialCo* is a leading multinational intra-logistics and materials handling OEM organization mainly focusing on industrial trucks and warehouse equipment. *IoTConsultingCo* is a €-700-million-revenue technology consultancy involved in this study focusing topics like 'Internet of Things (IoT)', 'Big Data Analytics', and 'Machine Learning'. *SoftwareCo* is a €20-billion-revenue software company with around 75000 employees worldwide. A strategic goal of the organization is to develop a software platform for the context of the 'Industrial Internet of Things and Services'.

The ADR method initially focuses on problem formulation with the goal to elicit MRs. Addressing not only the problem instance but a class of problems, ADR focuses on generating generalized knowledge (Sein et al. 2011). To define the problem space, I elicit MRs that apply for the class of problems that the ADR project aims to address. MRs reflect generic requirements that should be followed when implementing a specific kind of information system (Walls et al. 2004). I use triangulation and rely on rich data from both (1) a systematic literature review (SLR) and (2) data obtained from expert interviews with managers from *IndustrialCo* to gather MRs. Obtained MRs were discussed and refined in a focus group workshop with participants from all three organizations.

First, a SLR is conducted to identify existing knowledge on the problem. For conducting the review, I follow the well-established principles of Webster and Watson (2002) and vom Brocke et al. (2015). I perform keyword searches as depicted in Table 1. Due to the interdisciplinary nature of the work, I draw on (A) literature on 'digitized products' to consider existing work in the field of digital product innovation and engineering design technology, (B) 'service innovation, smart service systems, and servitization' to focus on the business process implications, and (C) literature that focuses on 'industrial manufacturing and the industrial service business' to consider the requirements arising from the industrial manufacturing context and industry characteristics. I limit the results to contributions published in the journals of the IS basket of 8 and in the top 10 journals on innovation as defined by Linton and Thongpapanl (2004). Additionally, proceedings of the *International Conference on Information Systems (ICIS)* were included. The search is restricted to articles published within the last 10 years. Out of the total of 2189 hits, 36 were considered after reading the abstract and applying firm inclusion (i.e., focus on physical goods getting augmented with digital technology, focus on digitization in industrial context, focus on innovative services based on digitized industrial products) and exclusion criteria (i.e., focus on product with solely physical or digital materiality, no link or transferability to industrial context, interview or editorial, no link to product- and service innovation).

Table 1. Search terms among the three relevant fields of research

Stream	Search term	Hits	Net hits
A	digit* OR Smart OR Platform	1189	Elimination of duplicates and application of exclusion criteria: 36
	pervasive* OR ubiqu*	177	
	generativ*	245	
	"internet of things" OR "internet of services"	51	
	(platform* OR product* OR service* OR software* OR technolog*) AND convergen*	88	
	"Product Service" OR "Product/Service" OR PPS	120	
B	("SD" OR "Service Dominant") And "Logic	8	
	"Service Innovation*"	60	
	"service system*" OR ecosystem*	188	
C	"Industrial Service*" OR "Industrial Internet"	25	
	"Installed Base" OR "Heavy Equipment"	17	
	"Machine Data"	21	

Second, interviews with industrial manufacturing experts were the main source of data collection to obtain deeper insights at one instance of the problem at *IndustrialCo*. Within the scope of the servitization trend (Lightfoot et al. 2013; Neely 2008), the overall goal of *IndustrialCo* is to pivot the existing, product-focused business models towards outcome-based service offerings and overcome the traditional goods-dominant logic (Herterich et al. 2016). Due to the long lifecycles of industrial products, however, *IndustrialCo* must set up the service platform as foundation for service innovation within the course of designing the next forklift truck generation today. Interview partners were selected by snowball sampling in the context of the case organizations (Patton 1990). Specifically, 14 digitization and service innovation managers of *IndustrialCo* were interviewed that aim at leveraging digitized industrial products in innovative service offerings. This ensured a high level of diversity for work context regarding the interview participants. NVivo 11 was used for analyzing and coding interview transcripts as well as secondary sources that were provided by the interviewees. MRs obtained from (1) the SLR and (2) expert interviews were consolidated and generalized resulting in generic MRs that abstract from the dedicated case context.

In the 'Building, Intervention, and Evaluation (BIE)' stage, MRs were addressed by means of a prototypical implementation in the context of *IndustrialCo's* service business. Expert interviews and a full-day ideation workshop with innovation mangers, service staff, digitization and product experts allowed the ADR team to identify (1) predictive maintenance and (2) fleet management as two innovative service offerings that instantiate the identified design principles. These two use cases were chosen to demonstrate the generative capacity of the digitized forklift trucks and the big data architecture. The implementation of the prototypes was highly iterative and organized in five agile sprints cycles supported by *IoTConsultingCo* and *SoftwareCo*.

Elicitation of meta-requirements and solution design

Elicitation of meta-requirements

According to a seminal paper on service innovation, Lusch and Nambisan (Lusch and Nambisan 2015), service platforms conceptualize the venue for value co-creation within service ecosystems and thus lead to service innovation. Specifically, resource liquefaction, resource density, and resource integration represent foundational elements of a service platform.

Existing literature considers resource liquefaction as a key concept for service innovation (Lusch and Nambisan 2015). It is suggested that operational data arising from digitized products should be detached from the physical product representation (Lusch and Nambisan 2015; Norman 2001). Operational data of digitized industrial products need to be integrated in existing information systems and made available to various organizational actors of the service ecosystem in a timely manner (Barrett et al. 2015; Lusch and Nambisan 2015). Besides operational data originating from the product itself, context information is equally important to understand how the product is used. Resource liquefaction unleashes generativity and thus enables opportunities for service innovation (Lusch and Nambisan 2015; Tilson et al. 2010). Terms like 'digital twin' or 'thing shadow' emerge to describe the duality of the physical and material representation of digitized industrial products (Porter and Heppelmann 2015). Insights obtained from case study research specify this even more precisely. *"Right now, we collect [operational product] data only in a limited manner. We seek to add telematics parameters to our web and e-business platform and collect these operational truck data." Head of IoT Development and Integration, IndustrialCo.* Thus, based on insights from literature and case study research, the first MR is theorized. *MR01: The design of digitized industrial products should provide open accessibility to exchange operational product data among actors in the service ecosystem.*

Second, *resource density* addresses the need to gain access to a sustainable combination of resources. Because of (1) the generative capacity of digital technology (Yoo et al. 2012; Yoo 2013; Zittrain 2006) and (2) the long lifecycles of industrial products (Blinn et al. 2008), potential future affordances of digitized industrial products cannot be anticipated today (Herterich et al. 2016). Hence, the material properties of digitized industrial products need to be flexible to be prepared to support potential changes in requirements. To effectively integrate new resources, literature suggests that layered modular product structures enhance the level of resource density and generativity compared to integrated structures or simple modular structures (Lusch and Nambisan 2015; Yoo et al. 2010). Thus, these aspects can be aggregated as a second MR. *MR02: The design of digitized industrial products should harness the generative capacity of digital technology to foster resource density.*

Third, *resource integration* addresses the rebundling and recombining of existing resources with new resources (Barrett et al. 2015; Lusch and Nambisan 2015). Especially in interdisciplinary contexts such as industrial manufacturing or smart cities, integration with existing systems is key as data from various actors has to be taken into account to realize innovative service offerings (Dreyer et al. 2017; Parmar et al. 2014; Porter and Heppelmann 2015). Consequently, digitized industrial products must be built in a way that allows for structural flexibility to interact with existing information systems, actors and changing product configurations. *"We must expect that what we are developing* *right now must be understood as a platform although it will be outdated very quickly - but we also need to think about the next steps." Global Director Sales and Service and Head of IoT Development and Integration, IndustrialCo.*

Industrial products are characterized by long lifecycles (Blinn et al. 2008). This results in a heterogeneous installed base in the field with disparate material properties. A key challenge is to collect operational data in a consistent way and derive steady and reliable insights (Lerch and Gotsch 2015). Standardized interfaces are needed to make the different systems work together (Kees et al. 2015). Based on insights obtained from existing work and interviews, the following MR emerges. *MR03: The design of digitized industrial products should allow for integration and recombination of data from different actors and information systems to support resource integration.*

Besides just monitoring the products, dedicated use cases require remote control functionalities to detect and resolve defects. Some smart services require switching industrial products into analysis or debugging mode or send other commands to the products to alter its mode of operation. Thus, requirement that digitized industrial products must offer the possibility to connect to the product remotely and control dedicated product functionality was identified when talking to interviewees. *"In some way, we not only have communication from the sensor to us. We also need to be able to log in on these trucks and run diagnostic software on it [...] If we had such a debug-mode, I could just log in on this truck and debug it no matter where the truck is." Director Connectivity and Digital Product Platform, IndustrialCo.* Consequently, the need for remote accessibility and bidirectional communication is formalized as follows. *MR04: The design of digitized industrial products should consider remote access functionalities to control, configure and debug digitized industrial products.*

Apart from shop floors and production facilities, industrial products are situated in remote locations and often connected via limited connectivity. Imagine off-shore wind turbines, forklift trucks, or elevators or within massive buildings that are characterized by bad reception of mobile internet. *"Because these trucks are sometimes not within the range of our local connections but the customer needs this data, we have to evaluate alternative connection possibilities." Head of IoT Development and Integration, IndustrialCo.* In such a setting, it is even more challenging to work with real-time data when required by the smart service. *"It's always difficult to work with real-time data because you need to send this data to the platform and the connection is not always reliable and* *able to transmit data in real-time" Head of IoT Development and Integration, IndustrialCo.* In terms of connectivity, the fifth MR is theorized as follows. *MR05: The design of digitized industrial products should consider limited connectivity and data transmission bandwidth.*

To obtain relevant insights and derive decisions based on operational product data, data analytics technology needs to be in place that can cope the enormous amounts of data. Literature distinguishes between two modes of data analytics that is also reflected in empirical data form the context of Chen et al. (2012) and Davenport (2007). First, incoming data must be analyzed in a timely manner to react to unforeseen events. *"When I get an error, I can immediately tell the customer to stop the operations to prevent any damages." Head of Field Service, IndustrialCo.* Second, pattern detection and advanced statistical analysis can be applied to substantial amounts of historic data. *"We need an exact analysis of historic operational data to understand how a truck is used and then define measures to make the next generation more cost efficient." Head of Product Marketing, IndustrialCo.* To support both modes of data analysis, the sixth MR is theorized as follows: *MR06: The design of digitized industrial products should allow for mechanisms to analyze (1) timely incoming operational data to immediately react to unforeseen events and (2) massive quantities of historic operational product data to generate insights from patterns in this data.*

In total, six MRs were elicited based on existing literature and insights from the problem formulation stage of the ADR project with *IndustrialCo*. Furthermore, meta-requirements were evaluated and refined in focus group workshops. Table 2 presents an overview of theorized MRs.

Table 2. Overview of identified meta-requirements with frequencies

ID	Meta-Requirement	Absolute and (Relative) Frequency	
		SLR	Interviews
01	The design of digitized industrial products should provide open accessibility to exchange operational product data among actors in the service ecosystem.	21 (0.583)	14 (1.000)
02	The design of digitized industrial products should harness the generative capacity of digital technology to foster resource density.	11 (0.306)	4 (0.333)
03	The design of digitized industrial products should allow for integration and recombination of data from different actors and information systems to support resource integration.	12 (0.333)	14 (1.000)
04	The design of digitized industrial products should consider remote access functionalities to control, configure and debug digitized industrial products.	14 (0.389)	10 (0.714)
05	The design of digitized industrial products should consider limited connectivity and data transmission bandwidth.	15 (0.417)	9 (0.643)
06	The design of digitized industrial products should allow for mechanisms to analyze (1) timely incoming operational data to immediately react to unforeseen events and (2) massive quantities of historic operational product data to generate insights from patterns in this data.	16 (0.444)	14 (1.000)

Building, intervention, and evaluation (BIE) of the solution design

In the BIE stage, electronic forklift trucks were augmented with digital technology based on open-source commodity hardware to continuously collect more than 100 distinct signals from the central control unit (i.e., CAN bus) of forklift trucks. In addition, longitudinal information (i.e., GPS data) and operational data on the battery of the trucks were collected. Since forklift trucks represent 'moving assets', wireless data transmission was implemented by leveraging the existing corporate wireless network of *IndustrialCo*. Drawing on public cloud service offerings, a 'big data platform' was set up to store and process the gathered data centrally. In agile and iterative sprint cycles, the prototypical implementation was refined until continuous reliable data collection and central data storage were possible continuously over a period of one month. In total, approximately 200 Gigabytes of operational product data was collected from both working and malfunctioning forklift trucks. Initially, *Kibana* was used as an explorative visualization tool to implement first queries and deep-dive into the data in data-exploration workshops with interdisciplinary participants.[1] An initial set of MRs was addressed by continuously collecting data and digitizing the forklift trucks. Unlike specified by MR06, analytical capabilities on the trucks themselves were not implemented initially, since this requirement did not arise from the service of choice. Capabilities in terms of processing power and execution environment, however, are earmarked in the product design by means of a single-board computer (SBC) attached to the forklift trucks. Furthermore, sending commands to the forklift trucks from remote (MR04), was also not implemented, since the control unit was accessed via the debugging interface that only can listen to onboard control unit signals and sensor data.

Furthermore, 'fleet management' and 'predictive maintenance' were identified as two concrete innovative services based on expert interviews and smart service innovation workshops. A prototypical dashboard with mobile capabilities was iteratively developed allowing to monitor the condition of trucks in real-time. Information provided by the dashboard is enriched by information about the service history of the truck (MR03). Drill-down capabilities to individual parts and components such as the battery, hydraulics, or the lifting system of forklift trucks are provided. In close cooperation with *IndustrialCo,* the prototype was mainly implemented by *SoftwareCo* and *IoTConsult-*

[1] Kibana is a state-of-the-art open source data visualization tool for Elasticsearch. It provides visualization capabilities on top of the content indexed on an Elasticsearch cluster.

ingCo as a foundation for service offerings in the fields of 'fleet management' and 'predictive maintenance'. Agile and iterative sprint cycles were used to refine the prototype. Figure 2 provides an overview on the dashboard of the prototypical implementation. Opinions on the implementation were discussed in one-on-one sessions with service managers and in a one-day evaluation workshop with the ADR team. Obtained insights from the prototypical implementation helped the ADR team to obtain further knowledge on the design of digitized industrial products. In parallel to technical implementation, service systems engineering (Böhmann et al. 2014) and business model ideation (Gassmann et al. 2015; Osterwalder et al. 2010) workshops were conducted with service experts from *IndustrialCo,* its affiliated dealer network and customers. Findings and learnings were documented in a central working documentation that was accessible for the entire ADR team along the individual sprint cycles, workshops and other activities related to the project.

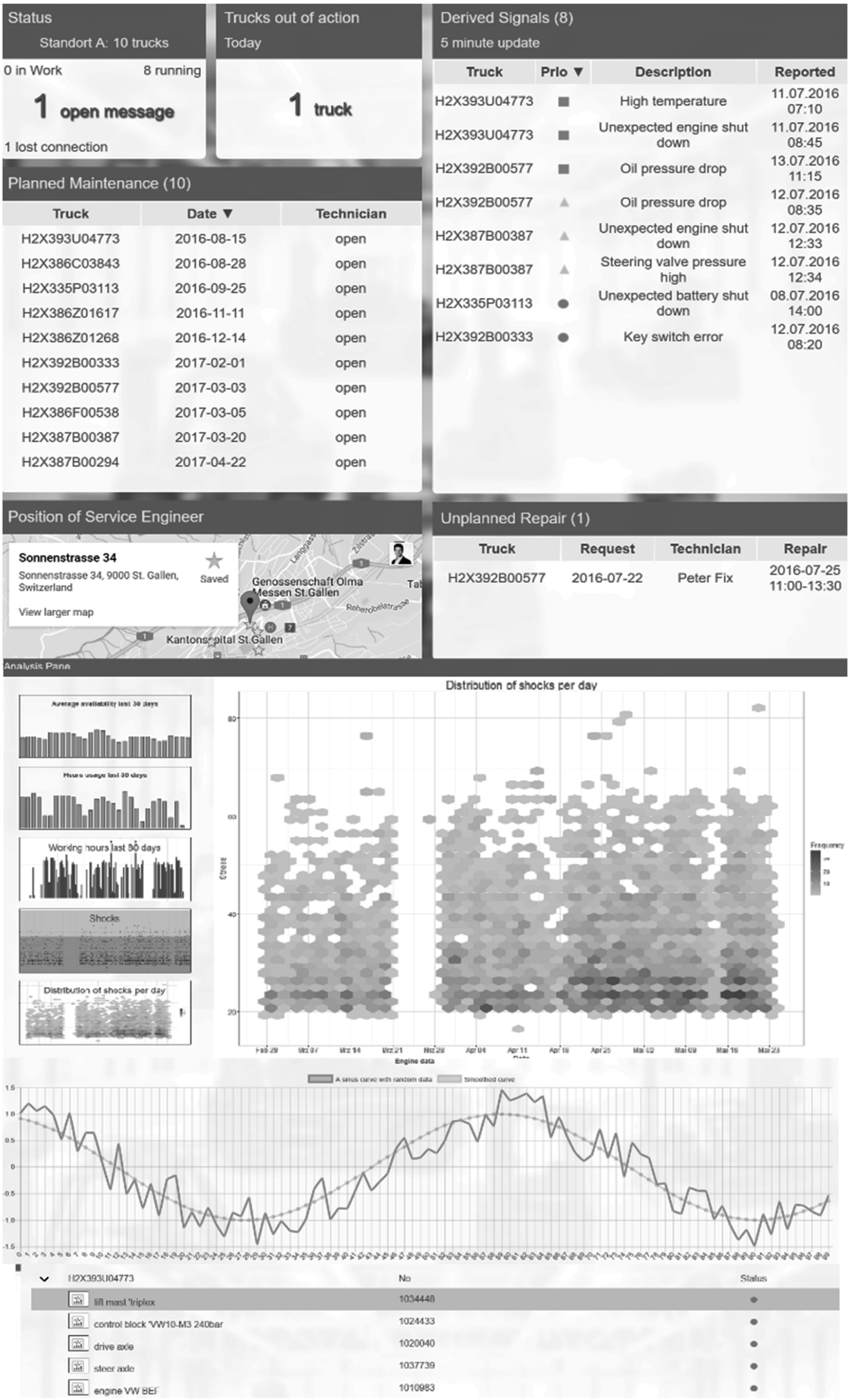


Figure 2. 'Real-time Predictive Maintenance and Fleet Management' dashboard after five iterative and agile sprint cycles

Formalization of learnings

The design knowledge obtained within the iterative sprint cycles of the ADR project can be formalized by verbalizing general design principles that contribute to the scientific body of knowledge on digitized products. The design principles represent generalized knowledge of the solution that was built within the course of the ADR project (Sein et al. 2011). Between the identified MRs and the design principles, a m:n relationship exists. Table 3 presents an overview of the final set of DPs within the framework of the layered modular architecture of digitized products (Yoo et al. 2012).

Table 3. Design principles of digitized industrial products for smart industrial service systems

ID	Design Principle	Addressed MRs	Device layer	Network layer	Service layer	Contents layer
01	To allow for open data accessibility and data exchange among actors, interfaces should be based on open protocols and standards.	MR01	●	●	●	●
02	To foster resource density and provide structural flexibility, the principles of a layered modular architecture should be adapted.	MR02	●	●	●	●
03	To connect to a broad variety of product models and generations, the interfaces between the layers must support open interfaces and standards.	MR01, MR02	●	●	●	●
04	To combine operational product data with other existing contextual business data from the own organization and other actors, operational product data need to be integrated with existing information systems via standardized interfaces to integrate resources and co-create value.	MR03			●	●
05	To have the possibility to control, configure and debug digitized products remotely, digitized industrial products must be designed in a way that allows secure bidirectional communication.	MR04	●	●		
06	To analyze large amounts of operational data that is relevant for product operations despite low network bandwidths, digitized industrial products should be able to analyze operational data on the edge in addition to analytical capabilities on a central digital platform.	MR05			●	●
07	To process both timely incoming operational data and massive quantities of historic data, the principles of the lambda architecture should be adapted.	MR06			●	●
08	To being able to react to unforeseen events in a timely manner, operational product data must be collected and analyzed in an adequate velocity.	MR06	●	●	●	
09	To generate insights from patterns in this data, operational product data must be collected continuously and in an adequate volume.	MR06	●	●	●	

DP01 refers to open standards for data exchange within the modular layered architecture as well as with existing systems. Initially, proprietary data formats were used for data exchange. In the final prototype, however, highly proprietary product data is transformed into JSON files due the open nature of the data format and its flexibility in terms of data structure based on attribute-value pairs. Furthermore, it was discussed to use MQTT as a lightweight messaging protocol. DP02 originates from the long lifecycles of industrial products. This implies that (1) various product models are in the field that must be compatible and (2) parts must be replaced over time. Loosely coupled modules and standardized interfaces (DP03) take this into account. In a later stage, the importance of open interfaces was furthermore considered as being relevant for smart service systems that incorporate additional actors in the service ecosystem. DP04 was formulated since operational product must be integrated and enriched with data from existing systems. Predictive maintenance services, for instance, can only be offered, if operational product data is contextualized with data about product master data, pervious maintenance activities, and customer data. DP05 came up when discussing an intermediate architecture of digitized forklift trucks with service managers in a focus group evaluation workshop. As more and more truck components have a digital materiality, it was noted that it must even be possible to send firmware updates to trucks to solve software-related issues remotely. DP06 focuses on the idea of ‘edge analytics’. It must be possible to analyze massive amounts of operational sensor of a single product instance without sending the data to a central platform because of bandwidth and connectivity limitations at the network layer. Thus, code (i.e., algorithms) can be sent to and run on industrial products in the field. Only the results of the in-depth (long-term) monitoring are transmitted to a central platform. DP07-09 refer to the back-end design of an analytics platform. To trigger timely events and recognize trends in historic data, the lambda architecture was finally identified as a valid data-processing architecture enabling two fundamental kinds of data processing for data-driven services.[2]

Discussion and conclusion

This paper reports on a 2.5-year lasting ADR project on designing digitized products to be used in innovative industrial service offerings. It contributes to the increasingly important body of knowledge on the generative design of physical products augmented with digital technology. Generic design knowledge is formalized as principles of form and function (causa formalis) (Gregor and Jones 2007). The final set of derived design principles can be considered as a first step towards a nascent design theory (Gregor

[2] The lambda architecture is a data-processing architecture to manage massive amounts of operational product data in an effective way. It distinguishes between a batch layer and a speed layer combining the advantages of both processing designs.

2009) and extend the existing state of knowledge on digitized products for several reasons. First, the elicited and evaluated DPs allow to publish design knowledge at an intermediate level and thus lays the foundation of a nascent information systems design theory (ISDT) of digitized industrial products (Heinrich and Schwabe 2014). Second, the results concretize the existing state of knowledge on the material properties and design of digitized products (Henfridsson and Bygstad 2013; Hylving et al. 2012; Yoo 2010, 2013). Finally, this work contributes to the ongoing conceptual convergence of literature on service innovation and the generative capacity of digitized products [1, 14, 17]. The paper raises awareness that the generative capacity of digitized products is based on adequate design decisions. Besides the theoretical contributions, the formalized design knowledge might help practitioners to design digitized products that effectively can be leveraged in the growing industrial service business. Specifically, managers must make adequate investment decisions today to build the foundation for future service innovation. Only if managers understand the implications of generative product design for the service innovation, proper investment decision can be made. Managers are required to consider generative digitized products as foundation for service innovation and smart service systems.

Although crafted from a thoroughly conducted ADR project and a solid foundation in existing literature, this study is not without limitations. First, I only had extensive access to IndustrialCo as one OEMs that aim at augmenting their industrial products with digital technology to be used in the industrial service business. Therefore, the DPs are still tentative and additional corroboration is needed. Second, although the guideline for the explorative interviews is based on an in-depth literature review in the field of potential organizational capabilities as well as the review of two experts within the field, it might still contain personal inclinations of the author. Third, derived MRs and DPs are valid for all kinds of industrial products and resulting service innovation. However, there might be a need to adapt both the MRs and DPs depending on industry specifics. For instance, design decisions for digitizing forklift trucks being ‘moving assets’ might differ from off-shore wind turbines or elevators. Future research is needed to corroborate the identified MRs and derived design principles with additional organization in the manufacturing industry and additional literature in the realm of engineering design technology. The validity of the results could be improved by using a quantitative approach.

Acknowledgements

This work has been supported by the *Swiss National Science Foundation (SNSF).* I furthermore would like to thank the project partners and member organizations of the *Competence Center Industrial Services and Enterprise Systems (CC ISES)* at the *Institute for Information Management (IWI-HSG)* at *University of St.Gallen* and Michael Spori for his valuable support throughout this ADR project.

References

Barrett, M., Davidson, E., Prabhu, J., and Vargo, S. L. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Quarterly* (39:1), pp. 135–154.

Blinn, N., Nüttgens, M., Schlicker, M., Thomas, O., and Walter, P. 2008. "Lebenszyklusmodelle hybrider Wertschöpfung: Modellimplikationen und Fallstudie an einem Beispiel des Maschinen- und Anlagenbaus," in *Proceedings of the Multikonferenz Wirtschaftsinformatik (MKWI)*, München, Germany.

Böhmann, T., Leimeister, J. M., and Möslein, K. 2014. "Service Systems Engineering: A Field for Future Information Systems Research," *Business & Information Systems Engineering* (6:1), pp. 73–79.

vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfault, R., and Cleven, A. 2015. "Standing on the Shoulders of Giants: Challenges and Recommendations of Literature Search in Information Systems Research," *Communications of the Association for Information Systems* (37:1), pp. 205–224.

Chen, H., Chiang, R. H., and Storey, V. C. 2012. "Business Intelligence and Analytics: From Big Data to Big Impact," *MIS Quarterly* (36:4), pp. 1165–1188.

Davenport, T. H. 2007. "Competing on Analytics," *Harvard Business Review* (84:1), pp. 98–107.

Dreyer, S., Olivotti, D., Lebek, B., and Breitner, M. 2017. "Towards a Smart Services Enabling Information Architecture for Installed Base Management in Manufacturing," in *Proceedings of the 13th International Conference on Wirtschaftsinformatik (WI)*, St. Gallen, Switzerland.

Eck, A., Uebernickel, F., and Brenner, W. 2015. "The Generative Capacity of Digital Artifacts: A Mapping of the Field," in *Proceedings of the 19th Pacific Asia Conference on Information System (PACIS)*, Singapore.

Eck, A., and Uebernickel, F. 2016. "Untangling Generativity: Two Perspectives on Unanticipated Change Produced by Diverse Actors," in *Proceedings of the 24th European Conference on Information Systems (ECIS)*, Istanbul, Turkey.

Eisenhardt, K. M., and Tabrizi, B. N. 1995. "Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry," *Administrative Science Quarterly* (40:1), pp. 84–110.

Fichman, R. G., Dos Santos, B. L., and Zheng, Z. E. 2014. "Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum," *MIS Quarterly* (38:2), pp. 329–353.

Gassmann, O., Frankenberger, K., and Csik, M. 2015. *The Business Model Navigator: 55 Models That Will Revolutionise Your Business*, Harlow, England: FT Press.

Göbel, H., and Cronholm, S. 2016. "Nascent Design Principles Enabling Digital Service Platforms," in *Proceedings of the 11th International Conference on Design Science Research in Information Systems and Technology (DESRIST)*, St. John, Canada.

Gregor, S., and Jones, D. 2007. "The Anatomy of a Design Theory," *Journal of the Association for Information Systems* (8:5), pp. 312–335.

Gregor, S. 2009. "Building Theory in the Sciences of the Artificial," in *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology (DESRIST)*, New York, NY.

Heinrich, P., and Schwabe, G. 2014. "Communicating Nascent Design Theories on Innovative Information Systems through Multi-Grounded Design Principles," in *Proceedings of the 9th International Conference on Design Science Research in Information Systems (DESRIST)*, Miami, FL.

Henderson, R. M., and Clark, K. B. 1990. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly* (35:1), pp. 9–30.

Henfridsson, O., and Bygstad, B. 2013. "The Generative Mechanisms of Digital Infrastructure Evolution," *MIS Quarterly* (37:3), pp. 896–931.

Herterich, M. M., Eck, A., and Uebernickel, F. 2016. “Exploring How Digitized Products Enable Industrial Service Innovation - An Affordance Perspective,” in *Proceedings of the 24th European Conference on Information Systems (ECIS)*, Istanbul, Turkey.

Herterich, M. M., and Mikusz, M. 2016. “Looking for a Few Good Concepts and Theories for Digitized Artifacts and Digital Innovation in a Material World,” in *Proceedings of the 37th International Conference on Information Systems (ICIS)*, Dublin, Ireland.

Herterich, M. M., Uebernickel, F., and Brenner, W. 2016. “Stepwise Evolution of Capabilities for Harnessing Digital Data Streams in Data-Driven Industrial Services,” *MIS Quarterly Executive* (15:4), pp. 297–318.

Hevner, A. R., March, S. T., Park, J., and Ram, S. 2004. “Design Science in Information Systems Research,” *MIS Quarterly* (28:1), pp. 75–105.

Hylving, L., Henfridsson, O., and Selander, L. 2012. “The Role of Dominant Design in a Product Developing Firm’s Digital Innovation,” *Journal of Information Technology Theory and Application* (13:2), pp. 5–21.

Kees, A., Oberlaender, A. M., Roeglinger, M., and Rosemann, M. 2015. “Understanding the Internet of Things: A Conceptualisation of Business-to-Thing (B2T) Interactions,” in *Proceedings of the 23rd European Conference on Information Systems (ECIS)*, Münster, Germany.

Lakhani, K. R., and Iansiti, M. 2014. “Digital Ubiquity: How Connections, Sensors, and Data are Revolutionizing Business,” *Harvard Business Review* (92:11), pp. 91–99.

Leonardi, P. M., and Barley, S. R. 2008. “Materiality and Change: Challenges to Building Better Theory about Technology and Organizing,” *Information and Organization* (18:3), pp. 159–176.

Lerch, C., and Gotsch, M. 2015. “Digitalized Product-Service Systems in Manufacturing Firms.,” *Research Technology Management* (58:5), pp. 45–52.

Lightfoot, H., Baines, T., and Smart, P. 2013. “The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends,” *International Journal of Operations & Production Management* (33:11–12), pp. 1408–1434.

Linton, J. D., and Thongpapanl, N. 2004. “Ranking the Technology Innovation Management Journals,” *Journal of Product Innovation Management* (21:2), pp. 123–139.

Lusch, R. F., and Nambisan, S. 2015. “Service Innovation: A Service-Dominant (SD) Logic Perspective,” *MIS Quarterly* (1:39), pp. 155–175.

Lusch, R. F., and Vargo, S. L. 2014. *Service-Dominant Logic: Premises, Perspectives, Possibilities*, Cambridge, England: Cambridge University Press.

Lyytinen, K., Yoo, Y., and Boland, R. J. 2015. "Digital Product Innovation within Four Classes of Innovation Networks," *Information Systems Journal* (26:1), pp. 47–75.

Maglio, P. 2015. "Editorial—Smart Service Systems, Human-Centered Service Systems, and the Mission of Service Science," *Service Science* (7:2), pp. ii–iii.

March, S. T., and Smith, G. F. 1995. "Design and Natural Science Research on Information Technology," *Decision Support Systems* (15:4), pp. 251–266.

Medina-Borja, A. 2015. "Editorial Column - Smart Things as Service Providers: A Call for Convergence of Disciplines to Build a Research Agenda for the Service Systems of the Future," *Service Science* (7:1), pp. ii–v.

Neely, A. 2008. "Exploring the Financial Consequences of the Servitization of Manufacturing," *Operations Management Research* (1:2), pp. 103–118.

Norman, R. 2001. *Reframing Business: When the Map Changes the Landscape*, Chichester, UK: Wiley.

Osterwalder, A., Pigneur, Y., and Clark, T. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*, Hoboken, NJ: Wiley.

Parmar, R., Mackenzie, I., Cohn, D., and Gann, D. 2014. "The New Patterns of Innovation.," *Harvard Business Review* (92:1/2), pp. 86–95.

Patton, M. Q. 1990. *Qualitative Evaluation and Research Methods*, Thousand Oaks, CA: Sage Publications.

Piccinini, E., Hanelt, A., Gregory, R., and Kolbe, L. 2015. "Transforming Industrial Business: The Impact of Digital Transformation on Automotive Organizations," in *Proceedings of the 36th International Conference on Information System (ICIS)*, Fort Worth, TX.

Porter, M. E., and Heppelmann, J. E. 2015. "How Smart, Connected Products Are Transforming Companies," *Harvard Business Review* (93:10), pp. 96–114.

Porter, M. E., and Heppelmann, J. E. 2014. "How Smart, Connected Products are Transforming Competition," *Harvard Business Review* (92:11), pp. 64–86.

Sawhney, M., Wolcott, R. C., and Arroniz, I. 2006. "The 12 Different Ways for Companies to Innovate," *Sloan Management Review* (47:3), pp. 28–34.

Sein, M., Henfridsson, O., Purao, S., Rossi, M., and Lindgren, R. 2011. "Action Design Research," *MIS Quarterly* (35:1), pp. 37–56.

Tilson, D., Lyytinen, K., and Sørensen, C. 2010. "Digital Infrastructures: The Missing IS Research Agenda," *Information Systems Research* (21:4), pp. 748–759.

Tiwana, A. 2014. *Platform Ecosystems: Aligning Architecture, Governance, and Strategy*, Amsterdam: Morgan Kaufman.

Ulaga, W., and Reinartz, W. J. 2011. "Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully," *Journal of Marketing* (75:6), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2016. "Institutions and Axioms: An Extension and Update of Service-Dominant Logic," *Journal of the Academy of Marketing Science* (44:1), pp. 5–23.

Vargo, S. L., Maglio, P. P., and Akaka, M. A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145–152.

Walls, J. G., Widmeyer, G. R., and El Sawy, O. A. 2004. "Assessing Information System Design Theory in Perspective: How Useful Was Our 1992 Initial Rendition?," *Journal of Information Technology Theory and Application* (6:2), pp. 43–58.

Walls, J. G., Widmeyer, G. R., and El Sawy, O. A. 1992. "Building an Information System Design Theory for Vigilant EIS," *Information Systems Research* (3:1), pp. 36–59.

Webster, J., and Watson, R. T. 2002. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," *MIS Quarterly* (26:2), pp. xiii–xxiii.

Woodard, C., and Clemons, E. 2014. "Modeling the Evolution of Generativity and the Emergence of Digital Ecosystems," in *Proceedings of the 35th International Conference on Information Systems (ICIS)*, Auckland, New Zealand.

Yoo, Y., Boland, R. J., Lyytinen, K., and Majchrzak, A. 2012. "Organizing for Innovation in the Digitized World," *Organization Science* (23:5), pp. 1398–1408.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724–735.

Yoo, Y. 2010. "Computing in Everyday Life: A Call for Research on Experiential Computing," *MIS Quarterly* (34:2), pp. 213–231.

Yoo, Y. 2013. “The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research?,” *Journal of the Association for Information Systems* (14:5), pp. 227–236.

Zittrain, J. L. 2006. “The Generative Internet,” *Harvard Law Review* (119:7), pp. 1974–2040.

Zittrain, J. 2006. *The Future of the Internet and How to Stop it*, New Haven, CT: Yale University Press.

C – **Article III**

Herterich, M.M., Eck, A. and Uebernickel, F. (2016). "Exploring How Digitized Products Enable Industrial Service Innovation - An Affordance Perspective". Completed Research Paper In: *Proceedings of the 24rd European Conference on Information Systems (ECIS)*. Istanbul, Turkey.

Exploring How Digitized Products Enable Industrial Service Innovation – An Affordance Perspective

Matthias M. Herterich
University of St.Gallen
9000 St.Gallen, Switzerland
matthias.herterich@unisg.ch

Alexander Eck
University of St.Gallen
9000 St.Gallen, Switzerland
alexander.eck@unisg.ch

Falk Uebernickel
University of St.Gallen
9000 St.Gallen, Switzerland
falk.uebernickel@unisg.ch

Abstract

This paper explores the impact of digitized products on industrial service innovation. Digital technologies equip physical products with versatile material properties that create a multitude of opportunities for value co-creation. In particular, product-complementing service offerings are an obvious field for investigating service innovation that leverage digitized products. We contribute to research on digitally enabled service systems that progressively emerge in industrial settings. Anchored in a revelatory case study in the intra-logistics industry, we explore how digitized products are put to innovative uses. Specifically, we take an affordance perspective to identify goal-oriented action potentials that arise from material properties of the digitized product and organizational use contexts in service systems. Interpreting case data, we show how original equipment manufacturers create the potential to (1) monitor and control industrial products remotely; (2) empower technical customer service; (3) manage, optimize, and integrate product operations; and (4) offer performance-based contracting of industrial products. Besides identifying affordances and demonstrating how digitized products enable novel configurations in service systems, we contribute to theory by (1) proposing a framework to conceptualize affordances of digitized products for service innovation and (2) linking the service-dominant logic with affordance theory.

Keywords: Service innovation, Servitization, Service-dominant logic, Digitized products, Generativity, Affordance theory.

Introduction

The traditional goods-dominant logic that relies on the exchange of industrial products for cash has come under tremendous competitive pressure. Original equipment manufacturers (OEMs) have realized that they need to intensify value co-creation in innovative service systems to meet their customers' genuine needs (Baines and Lightfoot 2013; Lightfoot et al. 2013; Neely 2008; Ulaga and Reinartz 2011). Against the backdrop or pervasive digitization, physical products increasingly become augmented with digital technology (Woodard et al. 2013; Yoo 2010). Whereas digitized consumer products rather have a hedonic value (Tuunanen et al. 2010) or increase convenience in our private daily lives, the arguably larger economic value lies in industrial contexts (Manyika et al. 2015). To address shrinking margins and growing competition, OEMs beginning to identify digitized industrial products as promising resources to intensify value co-creation with equipment operators. Their aim is to unlock the next level of service innovation on their servitization journeys.

Recent studies estimate that global spend by OEMs on digitizing industrial products and associated digital infrastructure will exceed US$-500 billion by 2020 (Accenture and General Electric Company 2015; Annunziata and Evans 2012). Particularly in the context of the industrial service business that is geared towards long product lifecycles, digitized products afford "dramatic new opportunities for service innovation" (Barrett et al. 2015, p. 135). OEMs, however, struggle in leveraging these opportunities (Herterich et al. 2016, 2015). The information systems (IS) domain recently turned to study how digital technology is put to innovative uses (Barrett et al. 2015; Lusch and Nambisan 2015; Lyytinen et al. 2015; Nambisan 2013). Scholars call for exploratory, yet theory-rooted research to better understand the generative capacity of digitized products and how it can be harnessed to gain competitive advantage (Barrett et al. 2015; Lusch and Nambisan 2015; Yoo et al. 2012). First attempts exist that investigate the impact of the physical and digital materiality of digitized industrial products on value co-creation in industrial service system configurations (Kees et al. 2015; Tuunanen et al. 2015; Zolnowski et al. 2011). However, to the best of our knowledge, no research focuses on affordances of digitized industrial products and resulting opportunities for service innovation. The purpose of this paper is to examine how digitized industrial products afford service innovation. We therefore formulate the following research question: *How do digitized products afford service innovation in industrial service systems?*

Based on a revelatory single case in the intra-logistics and materials handling industry, we identify potential uses of digitized industrial products for service innovation. To comprehensively conceptualize the arising potentials for service innovation, we draw upon affordance theory (Majchrzak and Markus 2013). Affordance theory allows us to focus on both technology features and the organizational use context.

The contribution of our work is threefold. We (1) identify four affordances of digitized industrial products in the context of the industrial service business. We (2) propose a framework for conceptualizing affordances of digitized products. We apply this framework by operationalizing *performance-based contracting of industrial equipment* as an exemplary affordance in the context of the industrial service business. We inform affordance theory and advance research on the generative capacity of digital technology, based on work on digital product innovation (Yoo 2010; Yoo et al. 2012) and socio-technical-systems (STS) theory (Bostrom and Heinen 1977) to conceptualize affordances in the context of service innovation. We (3) link S-D logic with affordance theory by describing potentials for service innovation based on digital technology as affordances taking into account both technological and organizational aspects. Thus, our work emphasizes the relevance of digitized products as operant resource for value co-creation in industrial service systems. We find that the service-dominant (S-D) logic needs to be extended by taking greater account of digital technology as operant resource for value co-creation.

This paper proceeds as follows. In Section 2, we provide the relevant theoretical background on digitized products, conceptualize service innovation by drawing on the S-D logic and introduce affordance theory. In Section 3, we describe the research methodology and introduce the case context. In Section 4, we present the identified affordances and go into detail for one exemplary affordance. Sections 5 and 6 discuss limitations, theoretical and managerial implications, as well as potential avenues for further research.

Theoretical foundation

The generative capacity of digitized products

Our world is increasingly affected by pervasive digital technology (Yoo 2010; Yoo et al. 2010). A key characteristic of this trend is the incorporation of digital technology into objects that previously had a purely physical materiality (Yoo et al. 2010). Especially when incorporated in industrial equipment with high requirements in terms of availability and utilization, digital technology seems to open infinite avenues for service innovation. Since the operations phase in the lifecycle of industrial products often spans decades (Ulaga and Reinartz 2011), OEMs expect significant benefits from digitized products for their service business. Among scholars, different conceptualizations exist that address digital augmentation of physical products. Table 1 provides an overview on relevant concepts describing the digitization of physical objects.

Table 1. Relevant concepts describing the digitization of physical objects

Concept	**Constituting elements**	**Sources**
Digitized products	Physical products augmented with digital technology resulting in new properties, namely programmability, addressability, communicability, memorability, sensibility, traceability and associability.	(Yoo 2010; Yoo et al. 2012, 2010)
Cyber-physical systems	Integrate physical processes and computing; employ sensors and actuators; save and evaluate recorded data; interact with physical/digital world; connect with each other; use globally available data and service; have multimodal human-machine interfaces; represent an evolution of embedded systems; feature system of systems characteristics.	(Lee 2008; Park et al. 2012)
Smart objects	Possess identity and store data; sense physical condition and environment; send actuation commands to other devices; possess decision-making capabilities; reach and receive information through networking.	(Kortuem et al. 2010; López et al. 2011)
Smart, connected products	Consist of physical components, smart components (i.e., sensors, microprocessors, data storage, controls, software), and connectivity.	(Porter and Heppelmann 2015, 2014)

Acknowledging the different aspects of the above-mentioned notions, we draw on the concept of *digitized products* shaped by Yoo et al. (2012, 2010) as the most comprehensive and scholarly recognized vocabulary for describing the phenomenon. Digitized product innovation deals with digital and physical materiality of products and the impact of digitization on product architecture (Leonardi and Barley 2008; Yoo 2010, 2013). The properties of physical products that incorporate digital components can be described comprehensively by drawing on the layered modular architecture as a well-established framework (Yoo et al. 2010).

Digitizing physical objects gives them new properties that facilitate anticipated and unanticipated opportunities for product and service innovation (Barrett et al. 2015; Nambisan 2013; Yoo et al. 2010). Hence, the (re)combination of a specific set of properties affords to produce novel products and services (Barrett et al. 2015). The term generativity describes this capacity of (digital) technology to be malleable by diverse groups of actors in unanticipated ways (Zittrain 2006). Recent studies provide first insights on how digitized products change value co-creation in an industrial context (Chowdhury 2014; Tuunanen et al. 2015; Zolnowski et al. 2011). However, examples that illustrate the generative capacity comprehensively in the light of service innovation are largely missing. Anchored in a revelatory case study, this work illustrates how the generative capacity of digitized products can be leveraged for service innovation in an industrial context.

Service innovation and S-D logic

Innovation of physical products is no longer relevant to be addressed individually (Barrett et al. 2015; Lusch and Nambisan 2015; Sawhney et al. 2006), since physical products are rather seen as distribution mechanisms for service provision (Vargo et al. 2008; Xu and Ilic 2014). The traditional goods-dominant logic fails to explain value co-creation in interwoven service systems with various actors (Vargo et al. 2008). Vargo and Lusch (2004, 2008) therefore proposed an S-D perspective that is widely accepted by scholars in various disciplines such as operations management, marketing and information systems (Bardhan et al. 2010; Beverungen 2011; Maglio and Spohrer 2008; Rai and Sambamurthy 2006). According to S-D logic, value is co-created based on the beneficial application of operant resources by actors in actor-to-actor networks or service ecosystems (Lusch and Nambisan 2015; Vargo et al. 2008). With the rise of the service business in the manufacturing industry (Lightfoot et al. 2013; Oliva and Kallenberg 2003; Ulaga and Reinartz 2011), S-D logic took root for also investigating the phenomenon of servitization (Ulaga and Reinartz 2011; Vargo and Lusch 2004). Servitization describes the shift of OEMs from a pure product focus to more integrated service offerings that can be conceptualized as service systems (Barrett et al. 2015; Lightfoot et al. 2013; Ulaga and Reinartz 2011). Following the S-D logic, service systems are generic value co-creation configurations of people, technology, and value propositions connecting internal and external service systems (Maglio and Spohrer 2008; Maglio et al. 2007).

Böhmann et al. (2014) argue that service systems increasingly rely on digital technology. In particular, they call for research that aims at investigating the impact of physical and digital materiality of products on service system configurations. Barrett et al. (2015) likewise recognize digital technology as a key resource for service innovation describing the “rebundling of diverse resources that create novel resources that are beneficial [...] to some actors in a given context” (Lusch and Nambisan 2015, p. 161). Digital technology is no longer exclusively understood as an *operand resource* (facilitator or enabler), but is also becoming an *operant resource* (initiator or actor) (Lusch and Nambisan 2015). Hence, digital technology shifts from a supporting role to a vital role for value co-creation. A great number of service systems are termed as *digital* or *digitally enabled*, since they draw on both the physical and digital materiality of digitized products as well as the expanded role of information technology as an operant resource (Yoo et al. 2010). Although the generative capacity of digitized products is identified as an essential driver for service innovation (Barrett et al. 2015), scholars and practitioners struggle to understand and describe how digitally enabled generativity is leveraged for service innovation (Lusch and Nambisan 2015; Nambisan 2013; Yoo 2013).

To explore how digitized products impact service innovation, we draw on the S-D logic for three major reasons. First, S-D logic takes into account both tangible products and intangible services (Grönroos and Helle 2010), since the service concept is employed as a "common denominator of all economic and social exchange" (Barrett et al. 2015, p. 142). Second, it focuses on value co-creation in service ecosystems and thus abstracts from interests of singular commercial actors. Third, it avoids the dyadic distinction between consumer and producer since it takes a network-centric perspective.

Affordance theory

Based on the ideas of *gestalt* theory, affordance theory has its origins in perceptual psychology (Gibson 1986). In its basic understanding, it describes how humans can interact with objects as a result of their material properties (Leonardi 2011). In recent years, IS research has increasingly focused on the mutually reinforcing and constituting relationship between social and technical forces (Leonardi and Barley 2008; Markus and Silver 2008; Seidel et al. 2013; Volkoff and Strong 2013; Yoo 2013) with the goal to better understand the generative nature of digital technology. This interest resulted in a renewed interest in affordance theory among IS scholars (Fayard and Weeks 2014; Leonardi 2011; Majchrzak and Markus 2013; Strong et al. 2014; Volkoff and Strong 2013; Zammuto et al. 2007).

According to affordance theory, digitized (industrial) products have a physical and digital materiality (Leonardi and Barley 2008; Yoo 2013) and thus feature specific *material properties.* These include physical material properties, referring to hardly changeable, visible and touchable properties (e.g., sensors and actuators), as well as digital material properties, referring to "what the software incorporated into an artifact can do by manipulating digital representations" (Yoo et al. 2012, p. 1398). An example for a digital material property of a digitized industrial product is an event-processing engine that continuously analyzes sensor data streams for pattern detection. Whereas the exclusive focus on material properties only results in describing technology characteristics, the relational nature of the affordance concept creates an understanding for the potential contextual value arising from the relationship between *material properties* and the *use context* (Majchrzak and Markus 2013; Markus and Silver 2008; Volkoff and Strong 2013). Although affordance theory in perceptual psychology originally focused on actors at an individual level (i.e., humans), the theory did undergo adaptations and extensions and thus serves as a valuable lens to investigate potentials for goal-oriented behavior at an organizational level (Seidel et al. 2013; Strong et al. 2014; Zammuto et al. 2007). While Markus and Silver understand affordances as "possibilities for goal-oriented action afforded to specified user groups by technical objects" (2008, p. 622), Zammuto et al. (2007) see affordances as capabilities of organizational actors when using a system. We follow the well-established conceptualization of Markus and Silver (2008) and understand affordances as *potential* behaviors (i.e., possibilities for action) of an actor for goal-oriented behavior to achieve an immediate concrete outcome (Majchrzak and Markus 2013).

We choose an affordance lens as a theoretical foundation to analyze the generative capacity of digitized products for service innovation for three reasons. First, it takes into account both the material properties of technology (technical subsystem) as well as the particular use context (social subsystem) (Majchrzak and Markus 2013; Yoo et al. 2012). Second, its focus on a particular use context is compatible with the contextual nature of the service innovation concept (Lusch and Nambisan 2015). Finally, it is able to take a consistent perspective on how actors are conceptualized in the S-D literature and literature on service innovation (Barrett et al. 2015; Lusch and Nambisan 2015). On that score, affordance theory is a valid theoretical lens for investigating how the generative capacity of digitized products fuels service innovation.

Research design and method

The goal of this research is to explore how the generative capacity of digitized products affords service innovation in an industrial context. To investigate the arising affordances in detail, we draw on an interpretive research design and apply a qualitative single case study approach because of three major reasons (Eisenhardt 1989; Myers 1997). First, we aim at investigating a novel phenomenon with yet undefined boundaries (Silverman 2010; Yin 2008). Second, qualitative research allows to generate a deep understanding of complex real-world phenomena within their social or organizational embedded contexts (Orlikowski and Lacono 2001). Third, we follow the principles of interpretive case study research (Klein and Myers 1999; Walsham 1995, 2006) and conduct a revelatory single case study (Yin 2008) to harness the full strength of human sense-making to explore the qualitative relational nature of affordances (Leonardi 2011; Pozzi et al. 2014).

Case context

Since affordances are highly contextual (Volkoff and Strong 2013), we briefly outline the setting of our case and present the organizational goals of the case organization as focal organizational actor of this study. The case organization is a leading multinational intra-logistics and materials handling organization mainly focusing on industrial trucks and warehouse equipment. It is split up into a manufacturing division and a sales & service division. In 2014, the case organization generated revenues exceeding US$-4 billion with around 20,000 employees. Comprising more than half of the staff, the service business is responsible for more than 45% of total revenue. Organized regionally, sales and service is occasionally performed by affiliated dealer organizations that exclusively focus on the products of the OEM, but can be considered as independent actors in the service ecosystem. Collectively, regional sales & service subsidiaries focus on selling and leasing new and refurbished industrial products to equipment operators. By far the largest share of revenue is generated by leasing products to equipment operators as beneficiary actors. Furthermore, the OEM offers product-related maintenance and repair services for its products as ‘ad hoc service’ or ‘full service’. Whereas ‘ad hoc service’ implies that equipment operators are invoiced for discrete maintenance or repair activities based on actual costs, ‘full service’ comprises routine maintenance and default repair activities based on defined service level agreement for a fixed service fee. Based on the data that we collected and analyzed, Table 2 provides an overview of main *organizational goals* for the service business.

Table 2. Organizational goals for the service business

Organizational goal (code frequency)	**Exemplary evidence**
Incrementally increase efficiency of existing service activities (48)	*“I think we are not efficient. That's why I'm currently running a project to change completely the maintenance that we do on short term rental, starting from a totally different point of view than we are doing today.” (#03, Head of full service business)*
	“In service, it’s all about maximizing efficiency. That means we need to improve the well-known first-time fix rate.” (#09, Director service marketing)
Intensify value co-creation with beneficiary actor organization (25)	*“We need to get rid of this thinking in terms of steel and iron. We need to sell more services instead of machines. We need to address our customers’ needs.” (#07, Director new business and product digitization)*
	“The customer wants to say: ‘Okay, you take care. I just want my truck run, work properly, have no down time, and that's fine’. We need to sell this as a chargeable service." (#03, Head of full service business)
Radical service innovation (57)	*“If I notice that a driver always presses the wrong buttons [...] then I sell him a driver training.” (#04, Managing director technology)*
	“Based on a cross-functional innovation initiative our goal is to offer entirely new services. [...] Today we can barely imagine the potential of our products augmented with digital technology.” (#09, Director service marketing)

Data collection

This study is part of a larger multi-year research program in which we accompany the case organization in their service innovation efforts. Thus, we had extensive access to experienced personnel with sound knowledge on service innovation initiatives within the case organization and its broader service network. Senior managers helped us to conduct snowball sampling and identify the right persons to discuss divergent perspectives on service innovation enabled by digitized products. Between 05/2015 and 11/2015 we conducted 14 formal interviews with managers responsible for service business, service innovation, and product digitization as well as with executives from group IT of the case organization. Formal interviews were based on an interview guideline, which we structured along the dimensions of STS theory, taking into account capability areas of digitized products (Sanislav and Miclea 2012) as well as existing frameworks and foundational work on value co-creation (Tuunanen et al. 2010, 2015; Vargo and Lusch 2008). We aimed at examining how the case organization leverages digitized products in its industrial services business. The interviews were designed to collect appropriate and sound data for later identification of affordances as relations between material properties of the organization's digitized industrial products and the specified use context of its service business. Supplemental activities within the larger research program allowed us to gather additional data by attending meetings, calls, and focus group workshops (Tremblay et al. 2010). We furthermore consulted internal documents and archival data for triangulation purposes (Yin 2008); all relevant data for this study is presented in Table 3 on the following page.

Data analysis

Two researchers analyzed the collected data line by line in an interwoven three-stage process of *open*, *axial* and *selective* coding following the recommendations of Strauss and Corbin (1990; 1997). For analyzing interview transcripts and internal documents, we used the software NVivo 11 as a computer-assisted qualitative data analysis tool. Figure 1 provides an overview on how we performed data analysis.

In the *open* coding stage, we aimed at identifying recurring concepts in the data with the goal of addressing concepts that guided us when compiling the interview guideline. At the same time, we tried to remain as open as possible to identify salient concepts from collected data. To corroborate our findings, we constantly compared the emerging codes coded by two researchers to identify common codes and harmonize different perspectives based on different codes.

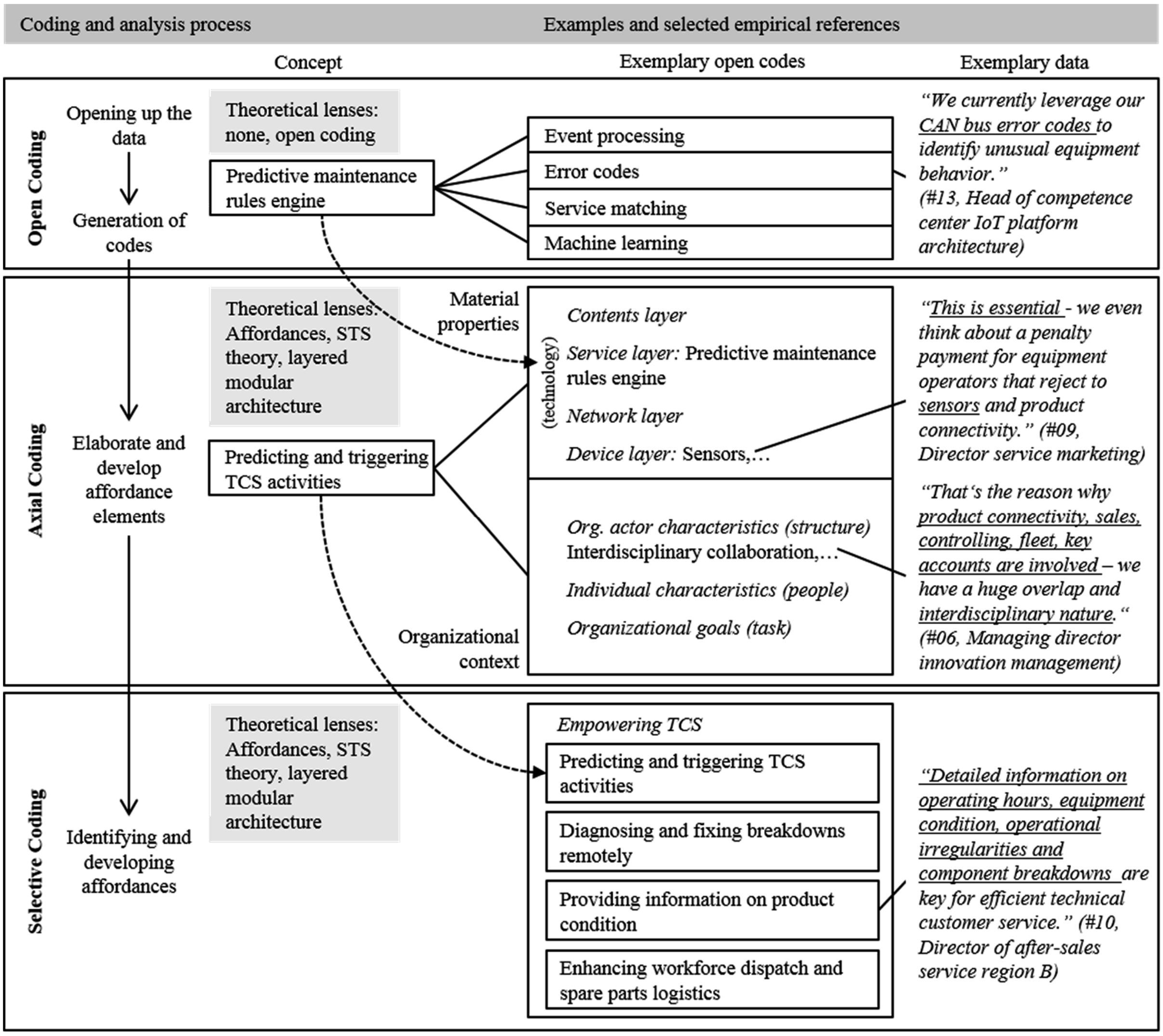
Table 3. Overview of collected and analyzed data

Data source	General information	Detailed information	Duration
Formal interviews	14 formal interviews Interview statistics: - ∑ 17:56h - μ: 1:17h - σ: 22:48min - 328 pages of text	#01, Managing director product marketing and communication #02, Vice President Sales & Service #03, Head of full service business #04, Managing director technology #05, Director of after-sales service region A #06, Managing director innovation management #07, Director new business and product digitization #08, Head of product marketing #09, Director service marketing #10, Director of after-sales service region B #11, Global Head of IT Operations #12, Director service standards #13, Director of after-sales and customer service #14, Head of competence center IoT platform architecture	84 min 60 min 105 min 99 min 64 min 54 min 65 min 50 min 101 min 79 min 30 min 93 min 109 min 83 min
Focus group workshops and meetings	4 full-day workshops and 2 meetings	Digitized equipment 2.0 proof-of-concept kickoff workshop Milestone review workshop I Milestone review workshop II Smart service systems innovation workshop Strategic meeting on servitization and service innovation Foresight workshop on flexible pricing models and outcome-based offerings	Full day Full day Full day Full day 4 hours 2 hours
Internal documents and archival data	Strategic service innovation concepts, technical documentations	Presentation on strategic service innovation clusters; 2x innovation board status presentations: project brief on business model transformation project (usage-based industrial equipment offerings and servitization), Internet of Things/telematics platform architecture proposal, sensor data payload calculations, target data model: operational industrial product data, network and connectivity requirements documentation	-

In the *axial* coding stage, we condensed categories by drawing on the affordance concept. This theoretical lens let us distinguish between material properties of digitized products and the organizational use contexts. We structured our analysis of affordances by drawing on the four dimensions of technology, structure, people and task originating from STS theory (Bostrom and Heinen 1977). STS theory is appropriate as a meta-framework, because it is simple, extensive, sufficiently well-defined, and anchored in existing literature (Seidel et al. 2013). Analogously to Seidel et al. (2013), we related the technology dimension to material properties, while the structure, people, and task dimensions helped us to specify organizational use contexts. Following the recommendations of Lusch an Nambisan (2015), we furthermore drew on the four dimensions of layered modular architecture to comprehensively describe the material properties of digitized products, namely device layer, network layer, service layer, and content layer (Yoo et al. 2010).

In the *selective* coding stage, we finally took affordances and STS theory as lenses to sharpen our focus on the relations between material properties and manifold use contexts that express arising affordances in the context of the industrial service business. In total, 850 codes were captured related to affordances (720 codes) and to organizational goals (130 codes).

Figure 1. Coding process with illustrations



Results

In the following, we describe affordances that arise from digitized products. We center our analysis on the OEM as our focal organizational actor. Although we cannot claim to identify an exhaustive set of affordances based on a single case study with sufficient claim for rigor, Table 4 on the following page provides an illustrative overview of affordances related to the service business identified in our data. Due to the focus of this work on service innovation and value co-creation, we exclusively address affordances in the context of the industrial service business. Hence, affordances that do not address value co-creation with other actors (e.g., using operational product data to engineer better products) are not regarded in this study.

Due to the limited space, we thoroughly discuss *performance-based contracting of industrial equipment* as an example to (1) provide evidence how affordances emerge based on our case and (2) give an illustrative example of how the generative capacity of digitized products lead to service innovation in the specific case of our case organization.

Table 4. Affordances for service innovation focusing on the OEM as organizational actor

Affordance	**Description**	**Code frequency**
Monitoring and controlling industrial products remotely	Monitoring and controlling industrial products remotely allows the OEM to generate operational visibility on their products in the field. The affordance furthermore allows controlling, updating, and resetting industrial products remotely. Transparency on product utilization and downtimes enable the OEM to determine the actual value generated by its products in value co-creation with the equipment operator as beneficiary. This affordance builds the foundation for other affordances.	152
Empowering TCS	Empowering technical customer service (TCS) allows to improve value co-creation in existing TCS systems. Harnessing the material properties of digitized products such as condition monitoring technology, TCS activities can be triggered and predicted based on operational data. At an individual level, service technicians can be empowered with rich information on equipment status aiming to increase TCS efficiency. In the same context, actuators allow that dedicated faults can be resolved remotely.	167
Managing, optimizing and integrating product operations	Managing, optimizing and integrating product operations allow the OEM to intensify value co-creation with other actors in the service ecosystem. OEMs can disseminate operational data from their own products or exploit data from other actors as a resource to co-create value in the service ecosystem. Exemplary immediate concrete outcomes are more adequate capacity scaling of the product fleet/installed base or vertical and horizontal integration in the service ecosystem resulting in innovative service offerings.	190
Performance-based contracting of industrial products	Performance-based contracting enables the OEM to change its product-dominated business models towards service-dominated offerings. By fully understanding how the beneficiary is using the products for value creation, flexible pricing mechanisms can be implemented that draw on contextual product usage data. Value co-creation and thus the relationship between OEM and equipment operator is intensified, since the OEM takes ongoing responsibility for product operations.	211

In the notion of S-D logic, “there is no value until an offering is used” (Lusch and Vargo 2006, p. 44). Shifting from goods-dominant product sales to offering industrial products based on fixed leasing rates was a first step of our case organization towards addressing evolving expectations of beneficiaries. Because of fluctuating production, usage of industrial products is rather volatile. Hence, equipment operators demand for flexible pricing models of industrial products. Triggered by this need, the organizational goal of the OEM arises to intensify value co-creation and in the process to offer more flexible usage-based offerings based on actual usage of the products.

"We no longer can just give the customer our equipment and then bill a monthly leasing rate. The customer wants to pay according cargo turnover or the number of trans-shipped tons or pallets. Digital technology is needed to monitor the equipment." (#04, Managing director technology)

"Our current key focus area is to sell our products as service offerings to dig deeper into the value creation of our customers. Therefore, we are in the middle of changing our business model towards dynamic pricing models, pricing on cargo turnover, per hour or per dedicated customer application." (#01, Managing director product marketing and communication)

"Do I have clean, dusty, moist conditions, abnormal environmental temperature on the shop floor? [...] We can no longer rely on checkboxes in some half-baked self-assessment questionnaires about operating conditions. Therefore, we start to leverage digitized equipment." (#06, Managing director innovation management)

We conceptualize the affordance of *performance-based contracting of industrial products* by focusing on the relation between material properties of digitized products (*technology*) and the use context described by organizational actor characteristics (*structure*), individual characteristics (*people*), and organizational goals (*task*). To comprehensively describe the material properties of digitized products, we furthermore draw on the dimensions of the layered modular architecture (Yoo et al. 2010). Following this structure, Table 5 presents a detailed overview on the constituting elements of this affordance.

Table 5. Offering industrial products as a service (outcome-based offerings) affordance

Affordance: Performance-based contracting of industrial products	
Material properties (technology)	**Use context**
Contents layer: Digital product twin, contextual information to interpret operational product data, on-demand billing information *Service layer:* Contextual pricing engine integrating operational product data, operator peculiarities, product application cost models *Network layer:* Bi-directional reliable and secure product connectivity with sufficient bandwidth *Device layer:* Physical products augmented with sensors and actuators	*Org. actor characteristics (structure):* Adequate organizational culture, incentive systems linked to goals of beneficiary and intensified value co-creation, partnerships with other actors for holistic value co-creation *Individual actor characteristics (people):* Individuals understand products as services; are able to identify and understand cost drivers based on operational product data, collaborate among various disciplines and organizational functions *Organizational goals (task):* Comprehensively addressing equipment operators' (beneficiary) needs, value-in-use instead of value-in-exchange, superior value co-creation and stronger relationships with beneficiaries

Focusing on the physical elements, industrial products need to be augmented with sensors and actuators that are required to be protected against on-site fraud or manipulation (*device layer*). For data transmission, bi-directional, reliable and secure product connectivity with sufficient bandwidth (*network layer*) is necessary to securely transmit various kinds of sensor data to a digital platform in the service layer.

"We decided […] to consequently equip every forklift truck […] with our connect kit." (#04, Managing director technology)

"Hardware security is super important. [...] We do not have any interest that a third party can access that raw operational product data in any manner." (#08, Head of product marketing)

"We use different technologies for ensuring a reliable connectivity based on the surroundings of the equipment. Wireless network or Bluetooth are two options [...] but the most widespread technology is 3G. More than 12.000 digitized, connected products result in around 350 GB of compressed mobile traffic per year." (#14, Head of competence center IoT platform architecture)

Based on historic usage data and contextual information (i.e. information on customer relationship or external data), pricing models can be generated. Based on a contextual pricing engine that draws on these models, actual costs for using the industrial product can be calculated. Resulting on-demand billing information needs to be fed into existing accounting systems of the OEM to bill the equipment operator (*service layer*). All information that is relevant for a specific truck is unified in a digital product twin – representing a holistic picture on the product condition at any point in time (*contents layer*).

"The crux of the matter in this topic is the level of detail that can be achieved on customer operations, actual equipment usage and performance, wear and tear, utilization, and finally availability. Visibility is the foundation for billing according to actual equipment performance. […] We need both data about the utilization and accurate cost models, to be able to bill the customers based on the added value our products created in their operations". (#06, Managing director innovation management)

Besides material properties of digitized products *(technology)*, the use context among the dimensions of *structure*, *people* and *task* give rise to the affordance of performance-based contracting of industrial products. First, an organizational culture that aims at a unique and phenomenological determination of value by the beneficiary actor (i.e., equipment operator) needs to be established. Incentive systems that are linked to goals of the equipment operator need to be set up at an organizational and individual level. For instance, need-oriented goals that are related to scale the truck fleet of the beneficiary by anticipating seasonal ups and downs in product usage might contradict traditional goals of the OEM such as selling the maximum number of products to the equipment operator.

"Changing the business model results in higher requirements in terms of product uptime, since we optimize existing equipment surpluses, which our customers had paid in the past. The absolute number of trucks that are used for the same intra-logistics operations will decrease; customers can do the same with less equipment." (#09, Director service marketing)

„Flexible pricing and performance-based contracting means to optimize equipment utilization in swaying demands such as seasonal peaks in agricultural applications. The equipment might then be smartly swapped to another equipment operator with full order books. However, we have to be aware that we sell less products. And this is not a bad thing." (#06, Managing director innovation management)

Performance-based contracting furthermore calls for interdisciplinary collaboration and draws on the employees of various organizational functions; intra-organizational collaboration between product engineering and service innovation division must be ensured.

"Part of this flexible price model team is of course the IoT connect team but also sales, controlling, customers, fleet managers and key account managers are involved." (#06, Managing director innovation management)

The organizational self-conception of the OEM must focus on value co-creation with other actors in the service ecosystem to comprehensively address the needs of other actors in the service ecosystem (*structure*).

"This transformation is complex and difficult to handle. We have to think about the fact that the entire organization is not trained for this – we are not computer scientists. And this will be the reason why we probably fail." (#10, Director of after-sales service region B)

Performance-based contracting means that individuals in various organizational functions understand products as services. They need to be able to identify and understand cost drivers based on operational product data, and collaborate among various disciplines and organizational functions *(people)*.

The affordance of performance-based contracting of industrial products allows the OEM to address the needs of the beneficiary more comprehensively and enables superior value co-creation resulting in stronger relationships with beneficiaries. In this way, the OEM focuses on value-in-use instead of value-in-exchange of their industrial products *(task).*

"Offering flexible pricing models and selling products as services require a high degree of interdisciplinary collaboration: we need digitization experts, IT experts, sales guys, controllers and marketing people work closely together. Furthermore, this involves in-depth research with key customers, fleet managers and key account managers. This results in organizational challenges such as cultural aspects, [...] reorganization of existing functions, and greater responsibilities for our organization. "(#06, Managing director innovation management)

Discussion and future research

We discuss the results of this paper in light of the existing body of knowledge on (1) S-D logic and service innovation, and (2) affordance theory and the generative capacity of digitized products. We furthermore (3) state major limitations of this work and propose how we would plan to continue our research.

S-D logic and service innovation. IT has been considered as an enabler and operand resource for value co-creation (Maglio and Spohrer 2008; Maglio et al. 2007; Vargo and Lusch 2004). Recent studies on servitization mainly recognize cultural aspects or organizational characteristics (e.g., size, competitive situation) as key drivers for service innovation (Eggert et al. 2011, 2014; Gebauer et al. 2005; Mathieu 2001). Service systems, however, increasingly rely on digital technology (Barrett et al. 2015; Böhmann et al. 2014). In line with existing work, this study illustrates how digitized products enable OEMs to gain transparency of their products as a prerequisite for flexible service offerings of any kind. OEMs as actors in service ecosystems are now able to leverage remotely monitored and controlled digitized products as *operant* resource. Thus, they are able to quantify how industrial products contribute to value co-creation. The actual value-in-use of industrial products augmented with digital technology can now be metered and billed adequately. Our work contributes by conceptualizing the generative capacity of digitized products as operant resource for digitally enabled service innovation (Lusch and Nambisan 2015). We furthermore identify operational product data of digitized products as an additional operant resource for value co-creation in service systems.

Affordance theory and the generative capacity of digitized products. As suggested by Zittrain (2006, p. 78) and Yoo et al. (2012), this work illustrates how the affordance concept can be used as an effective lens to understand the generative capacity of digitized products for service innovation. We contribute to IS-specific theory development in three ways. We (1) link affordance theory with S-D logic by discussing affordances from an S-D perspective. In particular, we demonstrate how digitized products are put to innovative uses by drawing on the value-in-use concept (Vargo and Lusch 2008; Vargo et al. 2008). In addition, we exemplify that an affordance lens is suitable to investigate service innovation fueled by digitized products (Barrett et al. 2015; Lusch and Nambisan 2015). By taking an organizational perspective, we (2) extend the body of knowledge on affordance studies in IS at an organizational level (Blegind Jensen and Dyrby 2013; Glowalla et al. 2014; Strong et al. 2014; Volkoff and Strong 2013). We (3) contribute to the theoretical discussion of how affordance theory is used in IS research on digital technology (Fayard and Weeks 2014). We therefore combine an affordance lens with the dimensions of STS theory and the layered modular architecture of digitized products as a meta-framework for a detailed conceptualization of arising affordances. The resulting structure can be used as an organizing framework in future affordance-related research, since it describes service systems based on loose couplings between the individual layers of digitized products and the use context in a comprehensive way. In particular, the framework takes into account (1) the physical and digital materiality of digitized products as well as (2) the use context at both an organizational and individual level.

Limitations and future research. The results should be viewed in light of the study's limitations. First, we have to note that partially different affordances could arise in other organizational settings or industries. Second, the identified codes and derived affordances might be interpreted differently by a different team of researchers. However, we aimed at developing a clear chain of evidence by taking into account multiple data sources. Nonetheless, we suggest to conduct additional studies in other industries than the intra-logistics industry to corroborate our findings. Despite those limitations, our explorative findings provide valuable insights and serve as an adequate conceptual grounding for further affordance-based studies on digitized products for service innovation. In particular, we plan to extend this work substantially aiming to (1) contribute to the body of knowledge on affordance dependencies, (2) affordance actualization, and (3) quantify the value of arising affordances.

First, our data suggests that *monitoring and controlling industrial products remotely* seems to be an essential affordance serving as foundation for other affordances. Volkoff and Strong (2013) coined the term 'basic affordances' to describe such foundational affordances. Similarly, TCS processes empowered by digitized products (i.e., condition monitoring) are fundamental for performance-based contracting, since highly efficient TCS processes allow OEMs to ensure product uptimes in a profitable way (Herterich et al. 2015). Strong et al. (2014) discuss how affordances seem to cascade, and introduce 'affordance dependencies' as a potential extension to affordance theory for describing this phenomenon. Volkoff et al. (2013) have a similar understanding and refer to 'basic affordances' and 'thematic affordances'. First studies exist that draw on the concept of affordance dependencies (Glowalla et al. 2014). Since the generative capacity of digitized products affords a multitude of opportunities to use the same material properties in different use contexts, we plan to extend the work at hand with follow-up research. Similar studies might find it worthwhile to further investigate affordance dependencies and thus advance affordance theory as proposed by Strong et al. (2014). For practitioners, insights on basic affordances as foundations for other affordances could be generated.

Second, this study in its current form exclusively focuses on affordance existence and perception (Bernhard et al. 2013; Glowalla et al. 2014; Pozzi et al. 2014) in the specific context of our case organization. Affordance actualization, however, deals with the "actions taken by actors as they take advantage of one or more affordances through their use of the technology to achieve immediate concrete outcomes in support of organizational goals" (Strong et al. 2014, p. 70). Extending the research towards affordance dependencies and affordance actualization might be an interesting lens to investigate the digital transformation journey of organizations. Such research might identify critical success factors as well as technical and organizational challenges that arise in the course of such endeavors.

Third, most of the current research taking an affordance perspective, including the study at hand, is either qualitative or conceptual. First ideas for quantitative research approaches on technology affordances have been proposed (Carte et al. 2015). Even more than in a consumer context, we argue that industrial service innovation fueled by digitized industrial products might serve as adequate settings for quantitative affordance research, since actors in industrial service ecosystem mostly focus on quantifiable utilitarian value themes as immediate concrete outcomes (Tuunanen et al. 2015). From a S-D logic perspective, we plan to draw on the value–in-use concept of digitized products in industrial service systems.

Conclusion

Drawing on a revelatory single case study, we explored how the generative capacity of digitized products enables service innovation and affects value co-creation in industrial service systems (Barrett et al. 2015). Our work is a first attempt to investigate how digitized products are used as an operant resource for service innovation in industrial service systems. In particular, we identified (1) *monitoring and controlling industrial products remotely*; (2) *empowering technical customer service*; (3) *managing, optimizing, and integrating product operations*; and (4) *performance-based contracting of industrial products* as four affordances of digitized products in the context of the industrial service business.

This study, however, goes beyond solitary affordance perception and contributes to theory-rooted knowledge on service innovation as an emerging and critical area for the IS discipline (Barrett et al. 2015). The identified affordances illustrate the generative capacity of digitized industrial products. Depending on the organizational use context, similar material properties of digitized products can be used differently. Furthermore, we propose a conceptual framework for describing affordances of digital technology. We instantiate this framework by operationalizing *performance-based contracting of industrial equipment* as an exemplary affordance in the context of the industrial service business. The framework takes into account existing work on digital product innovation (Yoo et al. 2012, 2010) and socio-technical-systems theory (Bostrom and Heinen 1977) to comprehensively describe affordances in the context of service innovation. Hence, our work addresses current research gaps (Volkoff and Strong 2013; Yoo et al. 2012) and provides an adequate conceptual grounding for further affordance-based studies on digitized products for service innovation. In particular, our findings serve as a foundation to identify dependencies between affordances of digitized industrial products for adequate affordance actualization.

Finally, we wish to outline two managerial implications. First, our findings show that digitized products the way OEMs will co-create value in innovative service systems fundamentally changes. Various affordances arise based on the generative capacity of digitized industrial products. The emergence of performance-based contracting as an exemplary affordance results in extensive managerial challenges for OEMs. Instead of maximizing ad hoc service revenues, OEMs must reevaluate organizational goals and establish highly efficient and proactive service operations to offer such performance-based contracts competitively and profitably. Second, fully harnessing the generative capacity of digitized products has extensive socio-technical implications. OEMs can harness the generative capacity of digitized products only when taking into account both technological and organizational aspects. Affordances such as outcome-based offerings require adequate organizational culture, adjusted organizational structure to increase interdisciplinary collaboration, and building up powerful service ecosystems to co-create value and meet the needs of the beneficiaries.

References

Accenture, and General Electric Company 2015. *Industrial Internet Insights Report*.

Annunziata, M., and Evans, P. C. 2012. *Industrial Internet: Pushing the Boundaries of Minds and Machines*, General Electric Company.

Baines, T., and Lightfoot, H. 2013. *Made to Serve: How Manufacturers Can Compete Through Servitization and Product Service Systems*, Chichester, West Sussex, United Kingdom: Wiley.

Bardhan, I. R., Demirkan, H., Kannan, P. K., Kauffman, R. J., and Sougstad, R. 2010. "An Interdisciplinary Perspective on IT Services Management and Service Science," *Journal of Management Information Systems* (26:4), pp. 13–64.

Barrett, M., Davidson, E., Prabhu, J., and Vargo, S. L. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Quarterly* (39:1), pp. 135–154.

Bernhard, E., Recker, J., and Burton-Jones, A. 2013. "Understanding the Actualization of Affordances: A Study in the Process Modeling Context," in *Proceedings of the 34th International Conference on Information Systems (ICIS)*, Milan, Italy.

Beverungen, D. 2011. "Mapping the Emerging Field of Service Science: Insights from a Citation Network and Cocitation Network Analysis," in *Proceedings of the 32nd International Conference on Information Systems (ICIS)*, Shanghai, China.

Blegind Jensen, T., and Dyrby, S. 2013. "Exploring Affordances of Facebook as a Social Media Platform in Political Campaigning," in *Proceedings of the 21st European Conference on Information Systems (ECIS)*, Utrecht, Netherlands.

Böhmann, T., Leimeister, J. M., and Möslein, K. 2014. "Service Systems Engineering: A Field for Future Information Systems Research," *Business & Information Systems Engineering* (6:1), pp. 73–79.

Bostrom, R. P., and Heinen, J. S. 1977. "MIS Problems and Failures: A Socio-Technical Perspective Part I: The Causes.," *MIS Quarterly* (1:3), pp. 17–32.

Carte, T., Schwarzkopf, A., and Wang, N. 2015. "How Should Technology Affordances Be Measured? An Initial Comparison of Two Approaches," in *Proceedings of the 21st Americas Conference on Information Systems (AMCIS)*, Puerto Rico.

Chowdhury, S. 2014. "Expanding Business from Products to Digital Services: Value Dimensions of Digital Services Enabled by Embedded Technology," in *Proceedings of the 8th Mediterranean Conference on Information Systems (MCIS)*.

Corbin, J., and Strauss, A. 1990. "Grounded Theory Research: Procedures, Canons, and Evaluative Criteria," *Qualitative Sociology* (13:1), pp. 3–21.

Eggert, A., Hogreve, J., Ulaga, W., and Muenkhoff, E. 2011. "Industrial Services, Product Innovations, and Firm Profitability: A Multiple-Group Latent Growth Curve Analysis," *Industrial Marketing Management* (40:5), pp. 661–670.

Eggert, A., Hogreve, J., Ulaga, W., and Muenkhoff, E. 2014. "Revenue and Profit Implications of Industrial Service Strategies," *Journal of Service Research* (17:1), pp. 23–39.

Eisenhardt, K. M. 1989. "Building Theories from Case Study Research," *Academy of Management Review* (14:4), pp. 532–550.

Fayard, A.-L., and Weeks, J. 2014. "Affordances for Practice," *Information and Organization* (24:4), pp. 236–249.

Gebauer, H., Fleisch, E., and Friedli, T. 2005. "Overcoming the Service Paradox in Manufacturing Companies," *European Management Journal* (23:1), pp. 14–26.

Gibson, J. J. 1986. *The Ecological Approach to Visual Perception*, London: Psychology Press.

Glowalla, P., Rosenkranz, C., and Sunyaev, A. 2014. "Evolution of IT Use: A Case of Business Intelligence System Transition," in *Proceedings of the 35th International Conference on Information Systems (ICIS)*, Auckland, New Zealand.

Grönroos, C., and Helle, P. 2010. "Adopting a Service Logic in Manufacturing: Conceptual Foundation and Metrics for Mutual Value Creation," *Journal of Service Management* (21:5), pp. 564–590.

Herterich, M., Buehnen, T., Uebernickel, F., and Brenner, W. 2016. "A Taxonomy of Industrial Service Systems Enabled by Digital Product Innovation," in *Proceedings of the 49th Hawaii International Conference on System Sciences (HICSS)*, Kauai, HI.

Herterich, M., Uebernickel, F., and Brenner, W. 2015. “Empowering Technical Customer Service by Cyber-Physical Industrial Equipment: Exploring Rationales, Opportunities, and Impediments,” in *Proceedings of the 19th Pacific Asia Conference on Information System (PACIS)*, Singapore.

Kees, A., Oberlaender, A. M., Roeglinger, M., and Rosemann, M. 2015. “Understanding the Internet of Things: A Conceptualisation of Business-to-Thing (B2T) Interactions,” in *Proceedings of the 23rd European Conference on Information Systems (ECIS)*, Münster, Germany.

Klein, H. K., and Myers, M. D. 1999. “A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems,” *MIS Quarterly* (23:1), pp. 67–93.

Kortuem, G., Kawsar, F., Fitton, D., and Sundramoorthy, V. 2010. “Smart Objects as Building Blocks for the Internet of Things,” *IEEE Internet Computing* (14:1), pp. 44–51.

Lee, E. A. 2008. “Cyber Physical Systems: Design Challenges,” in *Proceedings of the 11th International Symposium on Object Oriented Real-Time Distributed Computing (ISORC)*, Orlando, USA.

Leonardi, P. M., and Barley, S. R. 2008. “Materiality and Change: Challenges to Building Better Theory about Technology and Organizing,” *Information and Organization* (18:3), pp. 159–176.

Leonardi, P. M. 2011. “When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies,” *MIS Quarterly* (35:1), pp. 147–168.

Lightfoot, H., Baines, T., and Smart, P. 2013. “The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends,” *International Journal of Operations & Production Management* (33:11–12), pp. 1408–1434.

López, T. S., Ranasinghe, D. C., Patkai, B., and McFarlane, D. 2011. “Taxonomy, Technology and Applications of Smart Objects,” *Information Systems Frontiers* (13:2), pp. 281–300.

Lusch, R. F., and Nambisan, S. 2015. “Service Innovation: A Service-Dominant (SD) Logic Perspective,” *MIS Quarterly* (1:39), pp. 155–175.

Lusch, R. F., and Vargo, S. L. 2006. *The Service-Dominant Logic of Marketing. Dialog, Debate, and Directions*, Armonk, New York: Sharpe.

Lyytinen, K., Yoo, Y., and Boland, R. J. 2015. "Digital Product Innovation within Four Classes of Innovation Networks," *Information Systems Journal* (26:1), pp. 47–75.

Maglio, P., Bailey, J., and Gruhl, D. 2007. "Steps Toward a Science of Service Systems," *Computer* (40:1), pp. 71–77.

Maglio, P., and Spohrer, J. 2008. "Fundamentals of Service Science," *Journal of the Academy of Marketing Science* (36:1), pp. 18–20.

Majchrzak, A., and Markus, M. L. 2013. "Technology Affordances and Constraints in Management Information Systems (MIS)," in *Encyclopedia of Management Theory*, E. Kessler (ed.), Thousand Oaks, CA: Sage Publications, pp. 832–836.

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., et al. 2015. "Unlocking the Potential of the Internet of Things," in *McKinsey Global Institute*.

Markus, M. L., and Silver, M. S. 2008. "A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole's Concepts of Structural Features and Spirit," *Journal of the Association for Information Systems* (9:10), pp. 609–632.

Mathieu, V. 2001. "Product Services: From a Service Supporting the Product to a Service Supporting the Client," *Journal of Business & Industrial Marketing* (16:1), pp. 39–61.

Myers, M. D. 1997. "Qualitative Research in Information Systems," *MIS Quarterly* (21:2), pp. 241–242.

Nambisan, S. 2013. "Information Technology and Product/Service Innovation: A Brief Assessment and Some Suggestions for Future Research," *Journal of the Association for Information Systems* (14:4), pp. 215–226.

Neely, A. 2008. "Exploring the Financial Consequences of the Servitization of Manufacturing," *Operations Management Research* (1:2), pp. 103–118.

Oliva, R., and Kallenberg, R. 2003. "Managing the Transition from Products to Services," *International Journal of Service Industry Management* (14:2), pp. 160–172.

Orlikowski, W. J., and Lacono, C. S. 2001. "Desperately Seeking the 'IT' in IT Research - A Call to Theorizing the IT Artifact," *Information Systems Research* (12:2), p. 121.

Park, K.-J., Zheng, R., and Liu, X. 2012. "Cyber-Physical Systems: Milestones and Research Challenges," *Computer Communications* (36:1), pp. 1–7.

Porter, M. E., and Heppelmann, J. E. 2015. "How Smart, Connected Products Are Transforming Companies," *Harvard Business Review* (93:10), pp. 96–114.

Porter, M. E., and Heppelmann, J. E. 2014. "How Smart, Connected Products are Transforming Competition," *Harvard Business Review* (92:11), pp. 64–86.

Pozzi, G., Pigni, F., and Vitari, C. 2014. "Affordance Theory in the IS Discipline: A Review and Synthesis of the Literature," in *Proceedings of the 20th Americas Conference on Information Systems (AMCIS)*, Savannah, USA.

Rai, A., and Sambamurthy, V. 2006. "The Growth of Interest in Services Management: Opportunities for Information Systems Scholars," *Information Systems Research* (17:4), pp. 327–331.

Sanislav, T., and Miclea, L. 2012. "Cyber-Physical Systems-Concept, Challenges and Research Areas," *Journal of Control Engineering and Applied Informatics* (14:2), pp. 28–33.

Sawhney, M., Wolcott, R. C., and Arroniz, I. 2006. "The 12 Different Ways for Companies to Innovate," *Sloan Management Review* (47:3), pp. 28–34.

Seidel, S., Recker, J., and Vom Brocke, J. 2013. "Sensemaking and Sustainable Practicing: Functional Affordances of Information Systems in Green Transformations," *MIS Quarterly* (37:4), pp. 1275–1299.

Silverman, D. 2010. *Qualitative Research*, Thousand Oaks, CA: Sage Publications.

Strauss, A., and Corbin, J. M. 1997. *Grounded Theory in Practice*, Thousand Oaks, CA: Sage Publications.

Strong, D. M., Johnson, S. A., Tulu, B., Trudel, J., Volkoff, O., Pelletier, L. R., et al. 2014. "A Theory of Organization-EHR Affordance Actualization," *Journal of the Association for Information Systems* (15:2), pp. 53–85.

Tremblay, M. C., Hevner, A. R., and Berndt, D. J. 2010. "Focus Groups for Artifact Refinement and Evaluation in Design Research.," *Communications of the Association for Information Systems* (26:1), pp. 599–618.

Tuunanen, T., Hänninen, J., and Vartiainen, T. 2015. "Value Co-Creation for Cyber-Physical Systems in Mining and Construction Industry," in *Proceedings of the 21st Americas Conference on Information Systems (AMCIS)*, Puerto Rico.

Tuunanen, T., Myers, M. D., and Cassab, H. 2010. "A Conceptual Framework for Consumer Information Systems Development," *Pacific Asia Journal of the Association for Information Systems* (2:1), pp. 47–66.

Ulaga, W., and Reinartz, W. J. 2011. "Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully," *Journal of Marketing* (75:6), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2004. "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing* (68:1), pp. 1–17.

Vargo, S. L., and Lusch, R. F. 2008. "Service-Dominant Logic: Continuing the Evolution," *Journal of the Academy of Marketing Science* (36:1), pp. 1–10.

Vargo, S. L., Maglio, P. P., and Akaka, M. A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145–152.

Volkoff, O., and Strong, D. M. 2013. "Critical Realism and Affordances: Theorizing It-Associated Organizational Change Processes," *MIS Quarterly* (37:3), pp. 819–834.

Walsham, G. 2006. "Doing Interpretive Research," *European Journal of Information Systems* (15:3), pp. 320–330.

Walsham, G. 1995. "Interpretive Case Studies in IS Research: Nature and Method," *European Journal of Information Systems* (4:2), pp. 74–81.

Woodard, C. J., Ramasubbu, N., Tschang, F. T., and Sambamurthy, V. 2013. "Design Capital and Design Moves: The Logic of Digital Business Strategy," *MIS Quarterly* (37:2), pp. 537–564.

Xu, R., and Ilic, A. 2014. "Product as a Service: Enabling Physical Products as Service End-Points," in *Proceedings of the 35th International Conference on Information Systems (ICIS)*, Auckland, New Zealand.

Yin, R. K. 2008. *Case Study Research: Design and Methods*, Thousand Oaks, CA: Sage Publications.

Yoo, Y., Boland, R. J., Lyytinen, K., and Majchrzak, A. 2012. "Organizing for Innovation in the Digitized World," *Organization Science* (23:5), pp. 1398–1408.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724–735.

Yoo, Y. 2010. "Computing in Everyday Life: A Call for Research on Experiential Computing," *MIS Quarterly* (34:2), pp. 213–231.

Yoo, Y. 2013. "The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research?," *Journal of the Association for Information Systems* (14:5), pp. 227–236.

Zammuto, R. F., Griffith, T. L., Majchrzak, A., Dougherty, D. J., and Faraj, S. 2007. "Information Technology and the Changing Fabric of Organization," *Organization Science* (18:5), pp. 749–762.

Zittrain, J. 2006. *The Future of the Internet and How to Stop it*, New Haven, CT: Yale University Press.

Zolnowski, A., Schmitt, A. K., and Böhmann, T. 2011. "Understanding the Impact of Remote Service Technology on Service Business Models in Manufacturing: From Improving After-Sales Services to Building Service Ecosystems," in *Proceedings of the 19th European Conference on Information Systems (ECIS)*, Helsinki, Finland.

D – Article IV

Herterich, M.M., vom Brocke, J., and Brenner, W. (under review). "Service Innovation in a Material World – Exploring How Digitized Products Afford Smart Service Systems in Industrial Service Ecosystems". In: *Journal of Service Research*.

Service Innovation in a Material World – Exploring How Digitized Products Afford Smart Service Systems in Industrial Service Ecosystems[1]

Matthias M. Herterich [a, b] **Jan vom Brocke** [c] **Walter Brenner** [a]

matthias.herterich@unisg.ch jan.vom.brocke@uni.li walter.brenner@unisg.ch
matthias.herterich@stanford.edu

[a] University of St.Gallen
9000 St.Gallen, Switzerland

[b] Center for Design Research (CDR)
Stanford University, Stanford, USA

[c] University of Liechtenstein
9490 Vaduz, Liechtenstein

Abstract

This paper investigates how digitized products enable smart service systems in industrial service ecosystems. Physical products are pervasively augmented with digital technology, thereby affording new opportunities for smart service systems. For instance, new ways to maintain and operate digitized products more effectively and efficiently have emerged. Special challenges and opportunities have arisen in the context of industrial manufacturing, which is characterized by the long lifecycles of industrial products and interdisciplinary, networked organizational actors. Our research is rooted in a case study with forty-seven semi-structured interviews and a global archetypical industrial service ecosystem that comprises an original equipment manufacturer, an analytics organization, a product operator, and a maintenance, repair, and overhaul organization that use digitized products in smart service systems. Grounded in the data, our results illustrate how shared, organizational, and collective affordances are concatenated in a stepwise manner before smart service systems emerge. We also find that shared institutions and institutional work are central to the emergence of collective affordances and to developing them into smart service systems. For managers, this work contributes to clarifying how generative digitized products can be used resources to co-create value in interdisciplinary service ecosystems.

Keywords: Smart Service Systems, Digitized Products, Collective Affordances, Service Ecosystems, Service Innovation, Service-dominant Logic.

---

[1] This work is based on: Herterich, M. M., Eck, A., & Uebernickel, F. (2016) Exploring How Digitized Products Enable Industrial Service Innovation - An Affordance Perspective In: Proceedings of the 24th European Conference on Information Systems (ECIS). Istanbul, Turkey. Herterich, M., Uebernickel, F., & Brenner, W. (2015) Empowering Technical Customer Service by Cyber-Physical Industrial Equipment: Exploring Rationales, Opportunities, and Impediments In: Proceedings of the 19th Pacific Asia Conference on Information System (PACIS). Singapore.

Introduction

Physical products are increasingly augmented with digital technology (Lyytinen et al. 2015; Yoo et al. 2012; Yoo 2013). The resulting "porous and fluid" digital innovation (Nambisan et al. 2016, p. 225) culminates in striking opportunities to come up with innovative services (Barrett et al. 2015; Larivière et al. 2017; Lusch and Nambisan 2015; Nambisan et al. 2016). Digital innovation transcends organizational boundaries, as diverse organizations are involved in identifying unanticipated uses of digitized products (Lyytinen et al. 2015; Yoo et al. 2012; Zittrain 2006). For instance, an original equipment manufacturer (OEM) of elevators may seek to engineer better products by attaching sensors and actuators to its elevators in order to gather operational data from them (Tuunanen et al. 2015). For their part, analytics organizations (AOs) might be interested in harnessing the same data in order to offer data-driven services, such as determining the ideal time for maintenance activities, while maintenance and repair organizations (MROs) leverage the same sensors and actuators to diagnose elevators remotely based on the data suggested by the AO. Product operators (POs) might want to optimize elevator operations and integrate them into their existing installed base representing the total number of products in field. In the end, OEMs might experiment with service-oriented business models that are fed by actual product usage.

For three primary reasons, industrial manufacturing is an appropriate area in which to study emerging smart service systems that draw on digitized products (Tuunanen 2012; Tuunanen et al. 2015). First, industrial manufacturing's service-related businesses are rapidly increasing in number, as recent studies estimate that global investments in digitized products and associated digital infrastructure in industrial manufacturing will exceed US$ 500 billion by 2020 (Accenture and General Electric Company 2015; Annunziata and Evans 2012). In the course of the ongoing trend toward adding services to physical products (Baines and Lightfoot 2013; Lightfoot et al. 2013), digitized products are promising enablers of smart service systems. Second, innovation is no longer exclusively bound to the physical materiality of products or a single organizational actor (Barrett et al. 2015; Nambisan et al. 2016). Service ecosystems with interdisciplinary and networked actors have emerged as nexuses for value co-creation and have rendered obsolete the traditional goods-dominant logic that relies on the exchange of products for cash (Barrett et al. 2015; Lerch and Gotsch 2015; Lusch and Nambisan 2015; Porter and Heppelmann 2015; Ulaga and Reinartz 2011; Wünderlich et al. 2015). Third, the service business is geared toward the long lifecycles of industrial products (Baines and Lightfoot 2013; Fain et al. 2017; Lightfoot et al. 2013). Therefore, despite the resulting opportunities for smart service offerings, the highly complex and interdisciplinary nature of service innovation leaves product-centered organizations struggling to leverage the potential that arises from digitized products.

Theorizing about organizational practices in the process of appropriating technology has gained an increased attention in Information Systems (IS) studies (Avital and Te'eni 2009; Leonardi 2011; Orlikowski 2007; Strong et al. 2014; Svahn et al. 2017; Volkoff and Strong 2013; Zammuto et al. 2007). However, the studies in this field are limited by their organizational perspective, and they omit the mechanisms that facilitate service innovation in the interconnected and networked world. As a result, several scholars call for interdisciplinary research on the emergence of service innovation and the distributed innovation agency and dynamic interactions in smart service systems (Barrett et al. 2015; Lusch and Nambisan 2015; Nambisan et al. 2016; Wünderlich et al. 2015).

To the best of our knowledge, no research focuses on conceptualizing resulting collective affordances of digitized products and thus opportunities for service innovation and smart service systems in industrial service ecosystems. The purpose of this paper is to explore how digitized products enable service innovation in industrial service ecosystems. Hence, we formulate the following research question:

How do digitized products afford service innovation in industrial service ecosystems?

Rooted in a revelatory case study with forty-seven semi-structured interviews, this study explores how digitized products are used in fourteen organizational affordances by four archetypical organizational roles: OEMs, MROs, AOs, and POs. We transcend organizational boundaries by incorporating these four perspectives into a service ecosystem perspective and investigate how these organizational actors integrate their resources into smart service systems. We draw on the concept of affordances (Majchrzak and Markus 2013) and use the service-dominant (S-D) logic (Lusch and Vargo 2014; Vargo and Lusch 2004, 2016, 2008) as a theoretical perspective.

Our work makes three primary contributions to theory. First, it demonstrates how smart service systems emerge in interdisciplinary service ecosystems and transcend organizational boundaries. Smart service systems emerge in a stepwise manner, such that shared and organizational affordances are concatenated to collective affordances that spark smart service systems. Both technical and social shared institutions are identified as key elements in effectively exploiting the distributed innovation agency of generative digitized products in interdisciplinary service ecosystems. Second, this work links the S-D perspective with the affordance concept, thereby providing a conceptual foundation for how the generative capacity of digitized products leads to smart service systems and collective affordances in service ecosystems. Third, the study advances the body of knowledge on technology affordances by identifying dependencies between the concepts of shared and collective affordances (Leonardi 2013) at the organizational and ecosystem levels.

The rest of this paper proceeds as follows. Section 2 roots the phenomenon of interest — the emergence of smart service systems in the industrial service business — in the existing literature, while Section 3 introduces S-D logic and affordances as theoretical lenses for our investigation, and Section 4 describes the research methodology. Section 5 presents the results by introducing the material properties of digitized products as shared digital technology and by exploring how smart service systems emerge based on organizational and collective affordances. Section 6 discusses the implications of our work for theory and practice, and the paper closes by outlining limitations and potential avenues for further research in Section 7.

Phenomenon of interest: the emergence of smart service systems in the industrial service business

This study focusses on the emergence of smart service systems in the industrial service business. In this section, we first position our work in the service innovation literature to which we contribute. Then we highlight the specifics of service innovation in industrial manufacturing on which we constitute our qualitative case study of how digitized products afford smart service systems in industrial service ecosystems.

Digital product innovation and digitized products

As the material world becomes increasingly digitized, digital technology is incorporated into objects that previously were once purely physical objects (Barrett et al. 2015; Nambisan et al. 2016; Yoo et al. 2010). Early interdisciplinary research on digital product innovation at the crossroads of digitization, innovation, and the addition of services to physical products deals with the digital and physical materiality of digitized products and digitization's impact on product architecture (Leonardi and Barley 2008; Yoo 2010, 2013). The properties of digitized products can be described by drawing on the layered modular architecture as a well-established framework (Yoo et al. 2010). Physical and digital components are arranged in four layers — the device layer, the network layer, the service layer, and the contents layer — and are loosely coupled through standardized interfaces (Yoo et al. 2010). The (re)combination of a set of properties affords opportunities for innovation (Arthur 2009; Barrett et al. 2015; Nambisan et al. 2016; Nambisan 2013; Yoo et al. 2010) that are addressed by the term *generativity*, which refers to the capacity of (digital) technology to be malleable by diverse groups of actors in unanticipated ways (Nambisan 2013; Yoo et al. 2010; Zittrain 2006). First studies focus on the generative capacity of digital technology within an organization's boundaries (Berente et al. 2016; Leonardi 2011; Piccinini et al. 2015; Svahn et al. 2017).

However, unlike what these studies suggest, the context of digital technology is not limited by organizational boundaries (Nambisan et al. 2016). Therefore, the notion of *community-based generativity* is introduced (Nambisan et al. 2016). For instance, the potential of digitized products can be altered by other actors — referred to as "broad and varied audiences" (Zittrain 2006, p. 70) — after a product launch. The resulting ex-post innovation is particularly important in the context of industrial manufacturing, with its long product lifecycles. Depending on the collaboration of actors involved in product operations, distributed innovation agency arises (Nambisan et al. 2016, p. 225). This novel perspective is in its infancy, and first work takes an ecosystem perspective (Lyytinen et al. 2015). Although Lyytinen et al. (2015) focus solely on the physical product and its design process, other studies acknowledge the need for interdisciplinary and multidimensional research on the potential for service innovation (Nambisan et al. 2016). Table 1 summarizes the existing concepts that are relevant to the realm of digital product innovation.

Table 1. Relevant concepts from the realm of digital product innovation

Concept	Definition	Description	Guiding references
Digital innovation	New combinations of digital and physical components to produce new products (and services) by combining digital data from heterogeneous sources easily "to deliver diverse services, which dissolve product and industry boundaries".	Digital innovation is not limited to the scope digitized products. Research on digital innovation bridges between an intra-organizational innovation management perspective and research on digital products as platforms for distributed innovation.	Barrett et al. 2015; Nambisan et al. 2016; Yoo et al. 2010
Digital product innovation	Significantly new products and services that are either embodied in information and communication technologies or enabled by them.	Research on digitized product innovation and digitized products focuses on the characteristics of material properties of the physical and digital materiality of digitized products as new combination.	Lyytinen et al. 2015; Yoo 2010; Yoo et al. 2012, 2012, 2010
Generativity	The capacity of (digital) technology to be malleable by diverse groups of actors in unanticipated ways.	The generative capacity of digitized products is understood as the source for service innovation.	Zittrain 2006

Layered modular architecture	The layered modular architecture provides a conceptual framework by which digitized physical products are decomposed into loosely coupled components that are arranged on a device layer, network layer, service layer, and contents layer.	The layered modular architecture as a well-established framework helps to structure the components of digitized products and focus on relevant elements.	Yoo et al. 2010

Smart service systems in the industrial service business

Industrial manufacturing is undergoing a deep transformation as it becomes the nexus for value creation (Tuunanen et al. 2015; Wünderlich et al. 2015). This shift is also taken up in a scholarly context (Martín-Peña et al. 2017; v. Wangenheim et al. 2017). The term, "servitization" describes the shift of OEMs from focusing purely on products to embracing more integrated service offerings that can be conceptualized as service systems (Barrett et al. 2015; Lightfoot et al. 2013; Neely 2008; Ulaga and Reinartz 2011). Existing work on servitization focuses on the OEM as the dominant organization (Kindström and Kowalkowski 2009) and recognizes organizational characteristics as key drivers of service innovation (Eggert et al. 2011, 2014; Gebauer et al. 2005; Kindström et al. 2013; Mathieu 2001). However, in the digital and interconnected age, industrial products are now often augmented with digital technology, providing a foundation for a new wave of smart service innovation (Barrett et al. 2015; Böhmann et al. 2014; Maglio 2015; Nambisan et al. 2016; Wünderlich et al. 2015).

To identify holistically the specific characteristics and challenges in the industrial service business, we conducted a systematic literature review following the well-established methodology of Webster and Watson (2002). Table 2 on the following page presents an overview of the characteristics of the industrial service business, clustered among the generic dimensions that emerge from the S-D logic perspective.

Theoretical lens

We base our study on S-D logic and affordance theory, a theoretical foundation that provides a suitable terminology and theoretical lens through which to study the emergence of smart service systems in the industrial service business.

Innovation agency is no longer bound to the digital and physical materiality of digitized products. (Barrett et al. 2015; Lusch and Nambisan 2015; Sawhney et al. 2006). Instead, physical products are increasingly distribution mechanisms for service provision (Vargo et al. 2008; Xu and Ilic 2014) or platforms for service innovation (Lusch and Nambisan 2015).

Table 2. Characteristics of the Industrial Service Business along the dimensions of the service innovation framework

Dimension	Characteristic	Impact for this study	Guiding references
Service ecosystem	Interdisciplinary and diverse set of organizational actors	The industrial service business consists of an interdisciplinary actor network. Thus, taking only into account focal actors such as the OEM and beneficiary (e.g., customer organization) is not enough. Additional actors also contribute to value co-creation by integrating resources. This study therefore focuses on the entire industrial service ecosystem as unit of analysis.	Allmendinger and Lombreglia 2005; Lerch and Gotsch 2015; Lusch and Nambisan 2015; Porter and Heppelmann 2014; Vargo and Lusch 2011, 2008
Value co-creation	Servitization in manufacturing	As industrial products get more and more commoditized, the industrial service business is an increasingly important pillar in terms revenues and value co-creation. Complexity of industrial product and service offerings increases; complexity of industrial product and service offerings increases. Organizations must focus on their core competences and partner with other actors in the ecosystem. This development serves as a catalyst for service innovation, new modes of value co-creation, business models, and disrupts existing organizational structures.	Baines and Lightfoot 2013; Barrett et al. 2015; Eggert et al. 2011; Lightfoot et al. 2013; Lusch and Nambisan 2015, 2015; Neely 2008
	Outcome-based business models	Organization that traditional offer industrial products and services complementing product operations must switch towards more outcome-based offerings and pay-per-use business models that include. Unlike the goods-dominant logic, an S-D logic perspective with its concept of value-in-use can address these mechanics.	Ng et al. 2013; Porter and Heppelmann 2014
Digitized industrial products as service platform	Long lifecycles of industrial products	Due to the long lifecycles of industrial products, today's industrial products are the foundation of tomorrow's service business. As long lifecycles offer numerous opportunities for complementing services, the industrial services business can be considered as an adequate context for research on smart service systems.	Blinn and Nüttgens 2010; Fellmann et al. 2011
	Industrial products get augmented with digital technology	Industrial products are augmented with digital technology. Resulting digitized products are the foundation for smart service systems.	Barrett et al. 2015; Lyytinen et al. 2015; Nambisan et al. 2016
	Loosely coupled components	Industrial products consist of loosely coupled components that of the are manufactured by different suppliers. Physical and digital components provide an ideal context to study how individual parts contribute to the emergence of smart service systems.	Lyytinen et al. 2015; Yoo et al. 2012

Because of this new perspective, the traditional goods-dominant logic can no longer explain how value is co-created in emerging service systems with multiple actors (Vargo et al. 2008). Therefore, Vargo and Lusch (2004, 2008) propose the S-D logic as a novel, interdisciplinary perspective that is widely accepted by scholars in disciplines like operations management, marketing, and IS (Bardhan et al. 2010; Beverungen 2011; Maglio and Spohrer 2008; Rai and Sambamurthy 2006). Vargo and Lusch (2016, 2017) summarize the worldview of S-D logic in five axioms that take into account shared institutions in service ecosystems as systems for value co-creation. Table 3 presents an overview of the axioms.

Table 3. Overview on axioms of S-D logic perspective

ID	Axiom
A1	Service is the fundamental basis of exchange.
A2	Value is co-created by multiple actors, always including the beneficiary.
A3	All social and economic actors are resource integrators.
A4	Value is always uniquely and phenomenologically determined by the beneficiary.
A5	Value co-creation is coordinated through actor-generated institutions and institutional arrangements.

Acknowledging the foundations of S-D perspective as recently summarized in the axioms, Lusch and Nambisan (2015) develop a thinking framework for service innovation serving as a foundation for interdisciplinary research. In so doing, they derive service ecosystems, value co-creation, and service platforms as three central pillars for research on service innovation.

Service ecosystems. Service research has traditionally focused on dyadic relationships between the customer and the provider (Gummesson 2008). For, instance, Breidbach and Maglio (2016) identify eight distinct roles of service consumers and service providers as dyadic economic actor roles in technology-enabled value co-creation processes. However, the service ecosystem perspective goes beyond the established customer-provider dyad to describe “spontaneously sensing and responding spatial and temporal structures of largely loosely coupled, value-proposing social and economic actors interacting through institutions, technology, and language to (1) co-produce service offerings, (2) engage in mutual service provision, and (3) co-create value” (Vargo and Lusch 2011, p. 185). These eight components of the definition are described in Table 4 on the following page.

The service ecosystem perspective also emphasizes the role of *shared institutions* (e.g., roles, norms, meanings, symbols, practices, arrangements) and resource interaction among actors (Akaka and Vargo 2013; Breidbach and Maglio 2016; Edvardsson et al. 2011, 2014; Lusch and Nambisan 2015; Vargo and Lusch 2016).

Value co-creation. According to S-D logic, value is co-created based on the beneficial application of *operand* (facilitator or enabler) and *operant* (initiator or actor) resources by actors in service ecosystems (Lusch and Nambisan 2015; Vargo et al. 2008). Value is highly context-dependent and often elusive (Beirão et al. 2017; Vargo and Akaka 2012), so actors cannot deliver value so much as offer value propositions as invitations

Table 4. Overview on components of service ecosystems

Component	Description
Spontaneously sensing and responding	Actors interface with other actors and use their senses to determine how and when to respond or act. With the ascendance of information technology, the sensing and responding is more and more spontaneous.
Spatial and temporal structure	Actors and resources are arrayed over geographic space and temporal dimensions.
Largely loosely coupled	Largely loosely coupled d. Value proposing actors. Actors cannot create value for other actors but can make offers that have potential value and this occurs via value propositions.
Value proposing actors	Actors cannot create value for other actors but can make offers that have potential value and this occurs via value propositions.
Use of language, symbols, institutions and technology	To interface successfully, actors need a common language. They rely upon these and other social institutions (e.g. monetary systems, laws, etc.) to regulate interfacing and exchange. Finally, technology and especially innovation drives system evolution and performance.
Co-produce service offerings	Actors invite other actors to assist in the production of service offerings.
Engaging in mutual service provision	Actors do not get a free ride but must help other actors, via service exchange, either directly or indirectly (e.g. monetarily or generalized reciprocity).
Co-creating value	Actors, in the integration of service offerings with other resources (including other service offerings), create value which is unique to their situation and context.

to other actors to co-create value (Lusch and Nambisan 2015). Thus, the value of a specific technology or product depends on the configuration of the actors involved and their organizational goals and value propositions. This notion is reflected in the concepts of *value-in-use* and *value-in-context* (Vargo and Lusch 2004, 2008). Existing work on technology-enabled value co-creation calls for further research on the nature of value co-creation in complex multi-actor networks (Breidbach and Maglio 2016). Because of the complexity of value co-creation in service ecosystems, the concept of shared institutions moves into focus (Edvardsson et al. 2014; Vargo and Lusch 2016).

Service platforms. Service platforms are modular structures of tangible and intangible components (i.e., resources) that serve as venues for service innovation (Lusch and Nambisan 2015). In the digital age, service innovation increasingly depends on digital technology as a vital resource (Akaka and Vargo 2013; Barrett et al. 2015; Böhmann et al. 2014; Lusch and Nambisan 2015; Nambisan et al. 2016), but the role of digital technology as both operand and operant resource is not yet fully explored (Akaka and Vargo 2013; Breidbach and Maglio 2016).

Based on Spohrer, Maglio, Bailey, and Gruhl's (2007) well-established concept of service systems, the emerging concept of *smart* service systems addresses the rise of digital technology (Maglio 2015; Medina-Borja 2015; Wünderlich et al. 2015). The National Science Foundation (Medina-Borja 2015, p. 5) defines smart service systems as "co-creating configurations of people, technologies, organizations, and information that are capable of independent learning, adapting, and decision-making" (Medina-Borja 2015, p. 3). Focusing on the rise of service innovation, "smart service systems" describe systems that are capable of learning, dynamic adaptation, and decision-making based on the data received, transmitted, and/or processed to improve its response to a future situation. In smart service systems, digital technology is no longer exclusively an *operand resource*, but is also becoming an *operant resource* (Lusch and Nambisan 2015). Hence, digital technology shifts from a supporting role to a vital role for value co-creation. A great number of service systems are termed *digital* or *digitally enabled* since they draw on both the physical and digital materiality of digitized products and on the expanded role of digital technology as an operant resource (Yoo et al. 2010).

S-D logic and the concepts that are related to service innovation are well-suited to this investigation for three major reasons. First, S-D logic takes into account both tangible products and intangible services (Grönroos and Helle 2010), as the service concept is employed as a "common denominator of all economic and social exchange" (Barrett et al. 2015, p. 142). An S-D perspective is recommended when an investigation focuses on the resulting digital innovation that goes beyond the product perspective (Barrett et al. 2015; Nambisan et al. 2016). Second, the S-D logic enables us to focus on actor-networks, to abstract from the interests of singular commercial actors, and to avoid the dyadic distinction between consumer and producer. Third, the interdisciplinary nature of service innovation based on digitized products requires an interdisciplinary theoretical perspective. S-D logic is a well-established perspective in many disciplines and is often used in existing work in the context of the industrial service business (Grönroos and Helle 2010; Grönroos 2008). Table 5 on the following page summarizes the concepts that are relevant to digital product innovation.

Because of the malleability of digital technology and its resulting generative capacity, the functionality and uses of digital technology that is attached to physical products can no longer be regarded as deterministic (Yoo et al. 2012, 2010). The generative capacity of digitized products serves as the foundation for innovation of any kind (Nambisan 2013; Zittrain 2006) and has gained attention in interdisciplinary research (Leonardi and Barley 2008; Markus and Silver 2008; Seidel et al. 2013; Strong et al. 2014; Volkoff and Strong 2013; Yoo 2013). An affordance perspective allows the generative capacity of digital technology to be investigated by focusing on the relationship between digitized products and their use context within the industrial service ecosystem. It links between

Table 5. Relevant concepts from the realm of service innovation and S-D logic

Concept	Definition	Guiding references
Service platform	Modular structure that consists of tangible and intangible components (resources) and facilitates the interaction of actors and resources.	Barrett et al. 2015; Lusch and Nambisan 2015
Service ecosystem	Spontaneously sensing and responding spatial and temporal structure of largely loosely coupled, value-proposing social and economic actors interacting through institutions, technology, and language to (1) co-produce service offerings, (2) engage in mutual service provision, and (3) co-create value.	Akaka and Vargo 2013; Lusch and Nambisan 2015; Vargo and Lusch 2011
Value co-creation	The process and activities that underlie resource integration and incorporate different actor roles in the service ecosystem.	Lusch & Nambisan, 2015
Smart Service Systems	Co-creating configurations of people, technologies, organizations, and information that is capable of independent learning, adapting, and decision-making.	Maglio 2015; Medina-Borja 2015
Shared institutions	Social norms, rules, conventions, meanings, codified laws, symbols or practices that are shared among actors in terms of value co-creation.	Akaka and Vargo 2013; Beirão et al. 2017; Lusch and Nambisan 2015; Vargo and Lusch 2016
Resource integration practices	An actor's bundling and combining activity of both its own and other actor's resources.	Vargo and Lusch 2016

the materiality of an object or technology to its context of use (Fayard and Weeks 2014; Markus and Silver 2008; Zammuto et al. 2007). The origins of affordance theory, which initially describes how humans can interact with objects (Leonardi 2011), lie in the realm of perceptual psychology (Gibson 1986). We follow Strong et al. (2014) and Majchrzak and Markus (2013) in understanding an affordance as "the potential for behaviors associated with achieving an immediate concrete outcome and arising from the relation between an artifact and a goal-oriented actor or actors" (Strong et al. 2014, p. 12). According to affordance theory, digitized products have a physical and a digital materiality (Leonardi and Barley 2008; Yoo 2013), so they feature specific *material properties.* These include *physical* material properties, which refer to largely unchangeable, visible, and touchable properties (e.g., sensors and actuators), and *digital* material properties, which refer to "what the software incorporated into an artifact can do by manipulating digital representations" (Yoo et al. 2012, p. 1398). The relational nature of the affordance concept creates the potential contextual value that arises from the relationship between *material properties* and the *use context* (Majchrzak and Markus 2013; Markus and Silver 2008; Volkoff and Strong 2013). Nambisan et al. (2016) identify affordance theory as a promising lens through which to distinguish between investigating innovation outcomes and innovation processes in the context of a particular set of innovating actors.

Leonardi (2013) specifies types of affordances. The concept of *collective affordances* describes the use potentials of technology that are enacted by a group of actors. The concept of s*hared affordances* is also a group-level concept, but shared affordances describe differences in the use potential within a group of actors. This study adapts the notions of shared and collective affordances to the organizational and ecosystem levels in the context of industrial manufacturing because the transcending view of affordance theory allows value co-creation configurations to be investigated. In addition, they are interdisciplinary lenses that go beyond the study of technology features that are initially built into digital technology or digitized products, so they can overcome dichotomies regarding subject-object and agency-structure at various levels of analysis (Leonardi 2013; Tim et al. 2017; Zammuto et al. 2007). Affordance theory is also well-suited to explaining how a particular technology is used in a specific use context (Anderson and Robey 2017), as it avoids deterministic approaches that focus solely on the "impact" of digital technology (Robey and Boudreau 1999). This context-specificity is in line with the value-in-context concept pushed by the S-D logic literature (Breidbach and Maglio 2016; Edvardsson et al. 2011; Vargo and Akaka 2012; Vargo et al. 2008) and the contextual nature of service innovation (Lusch and Nambisan 2015). Table 6 summarizes the concepts from affordance theory that are relevant to the study at hand.

Table 6. Relevant concepts from affordance theory

Concept	Definition	Guiding references
Organizational affordance	Potential for behaviors associated with achieving an immediate concrete outcome and arising from the relation between material properties of an artefact and a goal-oriented actor or actors.	Majchrzak and Markus 2013; Strong et al. 2014
Shared affordance	Affordance that is shared by all members of a group by similar use of digital.	Leonardi 2013
Collective affordance	Affordance that is collectively created by members of a group, in the aggregate, which allows the group to do something that it could otherwise not accomplish.	Leonardi 2013

Research design and method

We conducted a single case study to address the study's research question (Yin 2008). Service innovation should be examined as "emergent, interactive, and dynamic as well as knowledge and communication-intense activity" (Barrett et al. 2015; Miles 2008, p. 117). Since we investigate a novel phenomenon with as yet undefined boundaries (Silverman 2010; Yin 2008), we must take the multidimensional nature of service ecosystems into account. Our unit of analysis is an archetypical industrial service ecosystem that comprises four archetypical actor organizations (Halinen and Törnroos 2005; Miles and Huberman 1994). This unit of analysis, with its "oscillating foci" (Beirão et al. 2017;

Chandler and Vargo 2011; Vargo and Lusch 2017), addresses the multidimensional nature of service ecosystems and allows us to reveal how smart service systems emerge simultaneously at both the organizational and the ecosystem level. We also follow the principles of interpretive case study research (Klein and Myers 1999; Walsham 1995, 2006), which allow us to explain complex-dependent real-world phenomena within their social or organizational embedded contexts (Eisenhardt 1989; Orlikowski and Lacono 2001). By harnessing the full strength of human sense-making, we can explore the qualitative relational nature of affordances in an archetypical service ecosystem (Leonardi 2011; Pozzi et al. 2014).

Description of industrial service ecosystem as case study's context

The research context plays a major role in any qualitative research inquiry (Brocke et al. 2016; Eisenhardt 1989; Yin 2008). S-D logic literature defines context as "a unique set of actors and the unique reciprocal links among them" (Chandler and Vargo 2011, p. 11). To allow for space and cover the distributed innovation agency of digitized products, our case study covers a typical set of organizational actors in the industrial service business, which existing work in in this domain identifies as OEMs, MRO organizations, and a PO (Becker et al. 2013; Gebauer et al. 2013; Meyer et al. 2011). In addition to suggestions from the theoretical body of knowledge, we add the dedicated role of an AO to our actor configuration in order to consider resources and integration practices related to data that is gathered from digitized products. Figure 1 provides a structural overview of the actors in the archetypical industrial service ecosystem as the unit of analysis.

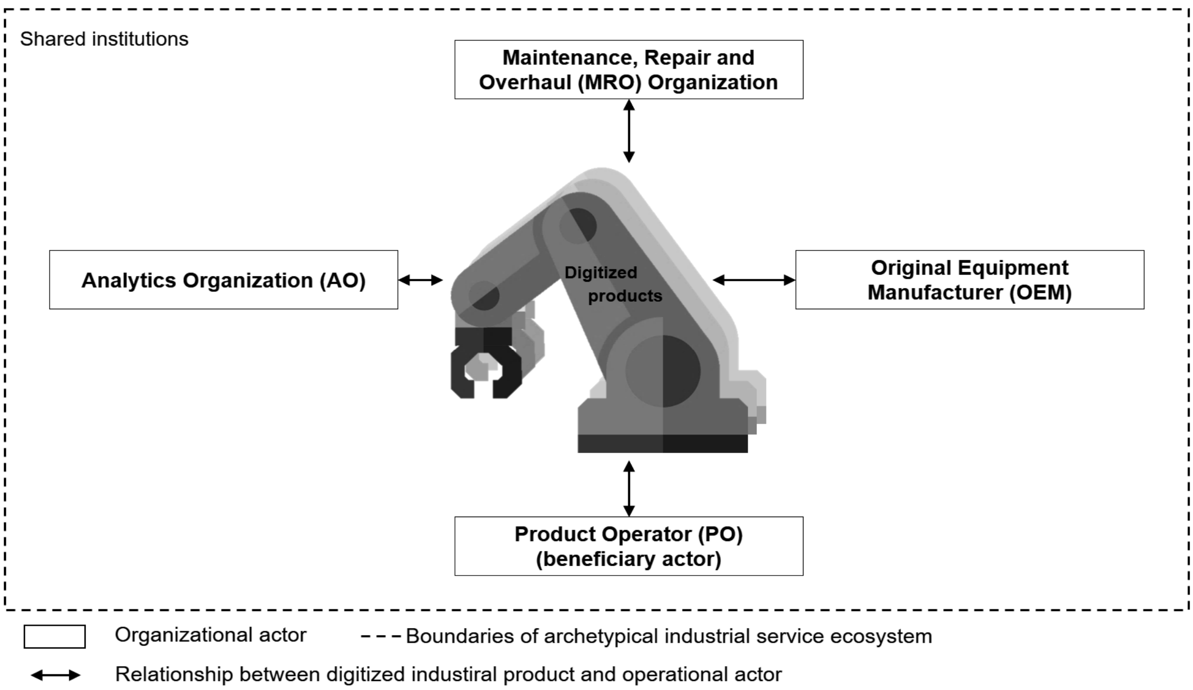


Figure 1. Structural overview of actors in archetypical industrial service ecosystem

Analytics organization (AO). We define AOs as actors that have the resources to deal with operational data in the context of industrial manufacturing. With the rise of digitized products and the resulting operational product data, established roles in industrial manufacturing face increasing problems in processing operational product data efficiently. As players with an emerging role in the industrial service ecosystem, AOs address this issue by providing dedicated resources for the collection, storage, and analysis of vast amounts of operational product data. AOs' competencies include big data analytics and real-time data streaming, and their organizational culture tends to be open-minded toward innovation and digital technology. The AO we feature in this work is established in industrial manufacturing, so it holds context-specific knowledge. The goals of this organizational actor are to create lock-in effects that will make it indispensable to the creation of value in the industrial service ecosystem of which it is a part.

MRO organization. MRO organizations are traditionally important in industrial contexts because of industrial products' long lifecycles. MRO organizations typically have a global footprint, although they are structured as regional entities. Their key objective is to ensure fault-free and safe operations and to reduce industrial products' downtime. Despite their traditional mindset, MROs' management recognizes the benefits of leveraging digital technology to increase operational efficiency in delivering MRO services to POs as customers. MRO organizations have strong relationships with POs, as MROs accompany industrial products throughout their lifecycles. The major goals of this organizational actor are to provide efficient activities and to differentiate themselves from their competitors by providing innovative smart service offerings during the operations phase of industrial products that address POs' needs.

OEM. As the originators of industrial products, OEMs are responsible for building them. Their organizational structure is product-focused, as their traditional focus is on engineering and manufacturing of industrial products. The organizational goals of OEMs focus on a product's beginning of life (BOL), predominantly driven by a goods-dominant logic (Ulaga and Reinartz 2011), by providing high-quality products at competitive prices. However, with servitization in manufacturing, OEMs are focusing more on the service business, although the principle of "value in exchange for cash" is still dominant. As one interviewee explained,

We need to get rid of this thinking in terms of steel and iron. We need to sell more services instead of machines. We need to address our customers' needs. (Director New Business and Product Digitization, OEM Organization).

In their role as the originator of industrial products, OEMs have the power to mobilize and orchestrate other actors in the service ecosystem (Gebauer et al. 2013).

Product operator (PO). POs are the main beneficiaries in the industrial service ecosystem, but buying industrial products does not satisfy their need, which is to pull together resources to co-create value with their customer organizations. The PO's key goals are to maximize the productivity of industrial products, to create transparency among industrial products and processes, and to pass this information on to customer organizations.

Data collection

This study leverages extensive and unique access to organizations involved in value co-creation in the industrial service business. Using theoretical sampling (Lapointe and Rivard 2007), we collected data from four typical organizational perspectives in the industrial service business. Between March 2014 and March 2017, we conducted interviews in industrial manufacturing organizations that are typical actors in an industrial service ecosystem. As the main method of data collection, two researchers conducted semi-structured interviews with mangers who were responsible for service business, service innovation, and product digitization, with executives from the IT department, and with chief technology officers (CTOs). In order to ensure that we had the perspectives of each of the four actors in the service ecosystem, we conducted interviews until we reached data saturation (Corbin and Strauss 2008). Our data collection focused on how smart service systems that transcend organizational boundaries emerge. To obtain a holistic, unbiased picture, we followed the recommendations of Eisenhardt and Graebner (2007) in recruiting interviewees from multiple hierarchical levels, from various organizational roles, and from distinct locations. In each organization, snowball sampling helped us to obtain an interdisciplinary yet focused perspective on the area of interest (Myers and Newman 2007) . Breadth and depth of perspectives were balanced by selecting interviews form different areas and hierarchical levels within the organizations to meet the demands of validity and reliability (Bryman and Bell 2015; Easterby-Smith et al. 2012). Interviews were designed to determine how digitized products are harnessed in both an organizational and an ecosystem context, so we structure the interview guideline along the theoretical concepts and frameworks discussed in Section 2. Forty-seven interviews were conducted that lasted an average of seventy-two minutes. All interviews were digitally recorded and transcribed, resulting in 864 pages of text.

In addition to interviews, supplemental activities like the design of and participation in full-day innovation workshops, focus groups (Tremblay et al. 2010), and conference calls were carried out. We also reviewed internal documentation, presentations, and other archival data from the organizations we interviewed. These activities allowed us to gather additional insights, triangulate findings obtained from interviews, and widen our insights into the primary topic (Yin 2008). Actor-specific summaries were compiled for all activities other than the semi-structured interviews. Detailed information on the interviews and supplemental activities are outlined in Table A1 in the appendix.

Data analysis

Two researchers analyzed the collected data line by line in an iterative manner following an interwoven three-stage process of *open*, *axial*, and *selective* coding and the recommendations of Strauss and Corbin (1990; 1997) in the realm of grounded theory (Glaser and Strauss 2009).

In the *open* coding stage, we identified recurring concepts in the data with the goal of addressing the concepts that guided us when we compiled the interview guideline. At the same time, we sought to remain as open as possible to identifying other salient concepts from the collected data. We compared the codes coded by the two researchers as they emerged to identify common codes and harmonize the perspectives.

In the *axial* coding stage, we condensed categories by drawing on the affordance concept. This theoretical lens let us distinguish between the material properties of digitized products and the use context at both the organizational and the ecosystem level (Chandler and Vargo 2011). To describe the physical and digital materiality of digitized products that are shared among organizational actors in the service ecosystem, we followed the recommendations of Lusch and Nambisan (2015) in drawing on the dimensions of the layered modular architecture to conceptualize the affordances' material properties (Yoo et al. 2010).

In the *selective* coding stage, we used an integrated perspective and focused on both the affordances that arose at an organizational level and the shared or collective affordances that transcended organizational boundaries within the service ecosystem and constituted interdisciplinary smart service systems. At an ecosystem level, we paid particular attention to the resource integration practices (Vargo and Lusch 2008) and the shared institutions (Edvardsson et al. 2014; Vargo and Lusch 2016) that described the nature of value co-creation in service ecosystems that consist of loosely coupled actors. When we stabilized our coding structure at the beginning of the selective coding stage, we compiled a coding scheme that was evaluated in two focus group workshops with practitioners that were not interviewees and with an interdisciplinary panel of senior researchers

(Tremblay et al. 2010). The evaluation workshops encouraged us to simplify the initial coding scheme to enhance understandability and to leave room for explorative findings.

To increase reliability and the quality of the final coding, two researchers coded an initial sample of eleven interviews in two iterations. After each iteration, inter-coder reliability was assessed using Cohen's kappa, a coefficient that measures whether the interrater proportion of agreement is greater than would be expected by chance (Rust and Cooil 1994). After the first round, we came up with a Cohen's kappa of .51. The largest inconsistencies in coding were discussed by the independent coders, and the coding scheme was revised for enhanced understandability and more consistent coding results. After the second round of coding, the Cohen's kappa increased to .77, a number that is significantly higher than the threshold level of .60 that indicates significant results (Landis and Koch 1977; Moore and Benbasat 1991). After finally coding the entire data set based on the coding scheme, we captured 2,611 codes. We used NVivo 11 as a computer-assisted qualitative data analysis tool to analyze the interview transcripts and internal documents. Figure 2 on the following page provides an overview of how we performed data analysis and an example of the applied coding scheme.

Results

Here we describe our observations concerning how smart service systems emerged in a stepwise manner in the context of our archetypical service ecosystem. We start by focusing on digitized products, the conceptualization of material properties, and shared affordances. Then we focus on individual actors' perspectives and identify their perceptions of organizational affordances. Finally, we describe how smart service systems emerge based on linking shared and organizational affordances into collective affordances.

Shared digital technology and shared affordances

Observation 1: *Industrial smart service systems draw on a fixed set of digitized products' material properties.*

Our data indicates that the smart service systems in the case we investigated draw on a fixed set of digitized products' key technologies that are shared among actors in the service ecosystem. Here, we identify these technologies and characterize them as material properties along the dimensions of the layered modular architecture (Yoo et al. 2010).

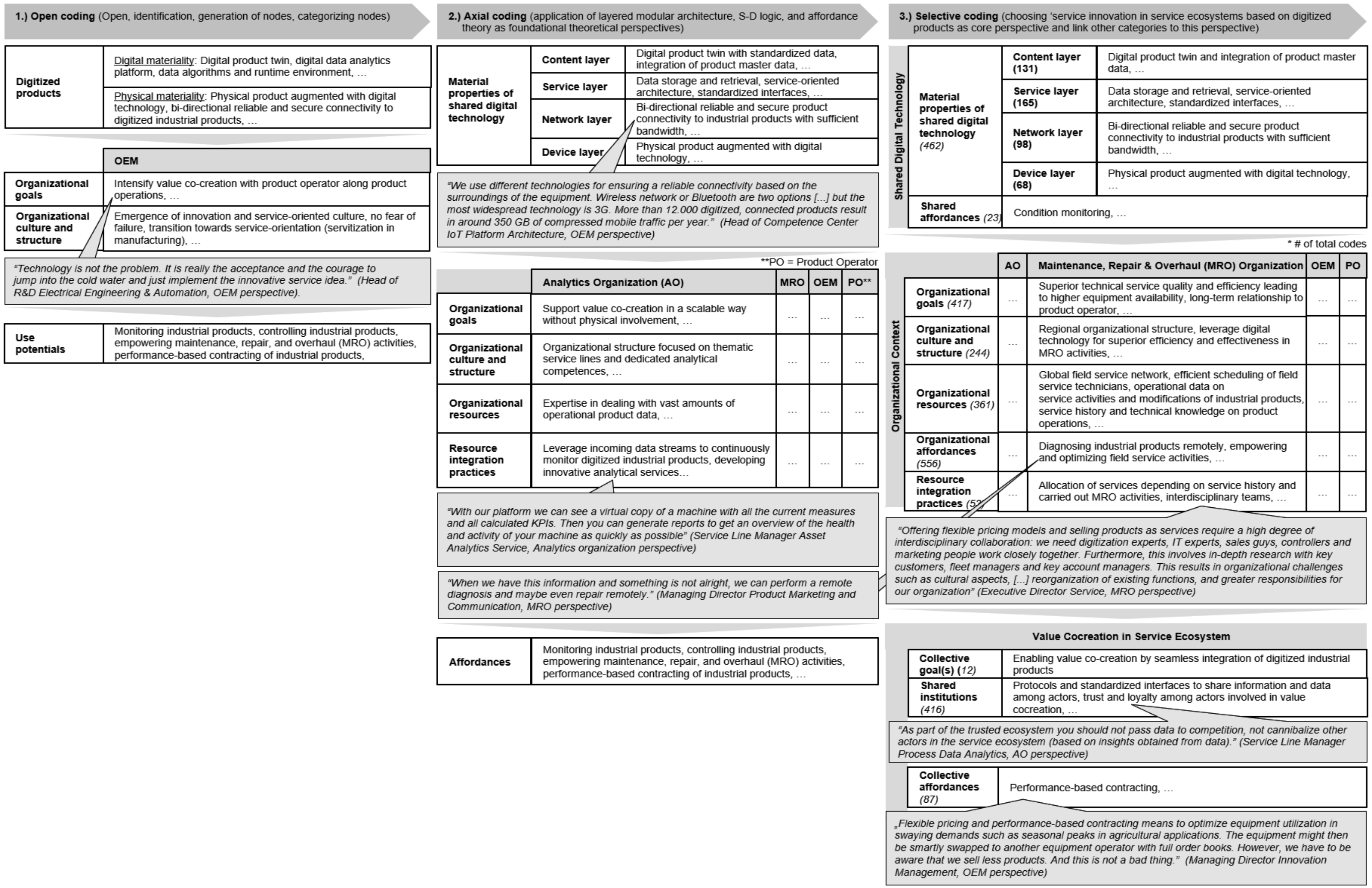


Figure 2. Stepwise open, axial, and selective coding with coding samples

Table 7 summarizes the nine material properties of the digitized products in our data that we identified as shared digital technology.

Table 7. Material properties of digitized products as shared digital technology

Dimension	Material property	Code frequency
Device layer	Physical products augmented with tamper-proof sensors and actuators	57
Network layer	Bi-directional, reliable and secure product connectivity with sufficient bandwidth	4
	Standardized interfaces, protocols and data structures	72
Service layer	Data storage and retrieval	27
	Incoming data-stream processing and timely alerts and notification	14
	Descriptive data analytics based on historic data	52
	Predictive data analytics based on historic and current data	22
Contents layer	Digital product twin and integration of product master data	102
	Consistency of operational product data throughout the installed base	5

Industrial products need to be augmented with sensors and actuators that protected them against on-site fraud and manipulation (*device layer*).

Consequently, we decided […] to equip every product […] with our connect kit to get operational product data without even asking our customers to pay for this. (Managing Director of Technology, OEM perspective)

Hardware security is super-important. [...] We do not have any interest in a third party's accessing that raw operational product data in any manner. (Head of Product Marketing, OEM perspective)

For data transmission, bi-directional, reliable, and secure product connectivity with sufficient bandwidth (*network layer*) is necessary to transmit various kinds of sensor data securely to a digital platform in the service layer.

We use various technologies to ensure a reliable connectivity […]. Wireless network and Bluetooth are two options [...], but the most widespread technology is 3G. More than 12,000 connected products result in around 350GB of compressed mobile traffic per year. (Head of Competence Center IoT Platform architecture, OEM perspective)

These actors also agree on standardized interfaces and protocols in the transport layer.

Technical standards like OPCUA that allow us to communicate directly with the cloud infrastructure or MQTT […] are relevant for interoperability and the development of data-driven services. (Service Product Manager, Out of the Box Analytics, AO perspective)

Digitized products have more than a physical materiality consisting of hardware and network components. After transmitting operational product data to a central platform, it can be stored and analyzed by analytical services (service layer).

An IoT platform must be able to store operational product data, irrespective of the age and configuration of the capturing device. Since we are obliged to meet statutory storage policies, we might need to save collected individual measurement values for fifteen years. This requirement can only be addressed by a central platform. (Vice President, Business Development and Operational Excellence, PO perspective)

To obtain insights and derive decisions based on operational product data, data analytics technology must be in place (service layer) that can deal with the enormous amounts of data. Two modes of data analysis are relevant. On the one hand, incoming data must be analyzed in a timely manner if the firm is to be able to react to unforeseen events.

When I get an error, I can immediately tell the customer to stop the operations to prevent damage. (Director, After-Sales Region A, MRO perspective)

On the other hand, pattern detection and advanced statistical analysis must also be applied to substantial amounts of historic data on both the central platform and on the digitized products themselves.

The machine is not just a simple transmitter of data; there is a lot of intelligence and computing power built in. For example, the product doesn't continuously send data but systematically connects to a central platform after aggregating and validating data. (Head of Competence Center IoT Platform Architecture, OEM perspective)

Finally, the service layer should offer the ability to update digital components of digitized products.

We want to be able to update the software on the products remotely over the air. (Global Head of IT Operations, OEM perspective)

Data that is received from industrial products must be consistent and comparable throughout the installed base and be able to provide a comprehensive reflection of the industrial product in the field (contents layer). Practitioners refer to this reflection as a "thing shadow" or a "digital twin."

Today, we can build digital twins that simulate and synchronize the characteristics and behavior of the real machine. (Head of Managed Service Analytics, AO perspective)

We need to establish a single point of truth and create an unambiguous data record over the product's whole lifecycle. (Managing Director, Innovation Management, OEM perspective)

Although there are several ways to equip digitized products with digital technology, actors in the industrial service ecosystem have a shared understanding of digitized products' configuration as a foundation for smart service systems.

[Irrespective of the final use cases], we aim at digitizing products in a highly standardized and scalable way. This includes hardware, sensors, software components, data management, data analysis, and the generation of insights. (Service Line Manager, Asset Analytics Services, AO perspective)

Observation 2: *Shared affordances are designed into digitized products and are largely actor-independent. They are perceived by multiple organizational actors and serve as the basic foundation for smart service systems.*

Following Leonardi (2013), we conceptualize affordances that multiple actors in the service ecosystem perceive as *shared affordances.* Our case data suggests that shared affordances are closely linked to the digitized products' material properties. Since shared affordances are closely tied to digitized products, we consider them to be context-agnostic.

"Condition monitoring" *(SA #01)* as an example of a shared affordance (SA) since it is perceived by multiple actors in our service ecosystem. Our data also indicates that its nature tends to be foundational and general, with no link to a specific actor in the service ecosystem.

If we can observe systemic phenomena in the installed base of the customers, they can draw CAPEX/OPEX decisions based on our system. This allows the MRO organization to work on strategic topics, the OEM can work on engineering better products, and operators can optimize the setup of its installed base and optimize utilization. (Service Manager, Out of the Box Analytics, AO perspective)

It would be valuable for us to have a platform where we have this transparency to see the condition and capacity use of all of our machines. (Head of Logistics and Process Performance, OEM perspective)

As we monitor assets, we can tie down a mean time between failures to specific equipment types and specific equipment configurations that will help us understand what requires more maintenance and what doesn't. (Director, Service Operations, MRO perspective)

Operational machine data is very interesting to us, as we can deduct performance measures […] and then we obtain visibility on how efficiently this equipment is actually used. (Director of Operations, PO perspective)

Organizational perspective and organizational affordances

Observation 3: *Organizational affordances are actor-specific and depend on the organizational context and goals of the organizational actor.*

Our data indicates that actors use digitized products as shared technology in certain ways; in other words, they leverage digitized products differently to co-create value depending on their organizational use context, including their organizational goals and the resources they integrate. For each actor role in our service ecosystem, we identify organizational affordances by taking into account respective organizational goals and use context, as suggested in the affordance research (Strong et al. 2014; Volkoff and Strong 2013).

Analytics Organization (AO) perspective. The overall goal of AOs is to provide scalable data-driven service offerings that support and enable value co-creation by gathering data, analyzing data, generating insights, and controlling digitized products. AOs' service offerings are purely digital and have no physical involvement, such as a global service workforce or other field activities.

We talk about scalable service operations that run automatically on a platform without any manual involvement. (Head of Analytical Service Development, AO perspective)

We identify organizational affordances that contribute to this overall goal. Table 8 on the following page provides an overview of the three organizational affordances perceived by the AO in our case context, and the required organizational resources.

The first of these organizational affordances is '"Performance benchmarking" *(AO #01)*, which allows AOs to provide descriptive statistics on product operations.

It starts with simple benchmarking topics—that is, comparisons between performances over time. This extends to more sophisticated issues." (Service Line Manager, Asset Analytics Services, AO perspective)

Table 8. Organizational affordances of AOs

Organizational goal(s) *(code frequency)*		
Scalable data-driven support and enablement of value co-creation in industrial service ecosystem *(16)*		
ID	**Organizational affordance**	**Exemplary required organizational resources**
AO #01	Performance benchmarking *(14)*	Expertise in dealing with vast amounts of operational sensor data *(16)*
AO #02	Event triggering *(36)*	Analyzing incoming data streams *(9)*
AO #03	Insights provisioning *(40)*	Basic contextual knowledge *(6)*
		Data science and processing capabilities *(24)*
		Digital platform *(32)*

Second, "Event triggering" allows the AO to trigger events based on anomalies and patterns by analyzing both incoming data and historic data *(AO #02).*

[One of our service offerings] just triggers machine halts or switching parameters between A and B. Customers can either do this manually based on the insights that we provide or trust our system. I think that this will start small: When introducing such a system, an employee will have to confirm "OK," "OK," "OK." When he has pressed "OK" for two years, and the decisions were good ones, he will finally let our system take over." (Service Line Manager Energy Management, AO perspective)

Third, "Insights provisioning" afford AOs the ability to provide insights on product operations to other actors in the service ecosystem (AO #03).

We aimed at providing value services instead of hotlines or support with problems. Therefore, we have established various service lines that provide insights and various kinds of value to customers. (Service Line Manager, Plant Cloud Services, AO perspective)

For this affordance, data must be shared with other actors, which can be done via a digital platform.

We need a digital platform that allows us to address data-sharing topics in a goal-oriented way. (Service Line Manager, Process Data Analytics, AO perspective)

All affordances contribute to the organizational goal of providing scalable service offerings.

For all our digital services, we have to collect data at the product operator, analyze data, and be able to provide insights in any form. This brought us to the idea of establishing a digital platform that […] enables us to do that in a scalable way. (Service Line Manager, Plant Cloud Services, AO perspective)

OEM perspective. The goal of OEMs is to provide superior industrial products at competitive prices.

We are curious about actual product usage in the field. By analyzing the actual usage data, we can identify how often a specific function is used over the life of a truck and can redesign the functionality accordingly [or] make the next generation more cost-efficient. (Head of Product Marketing, OEM perspective)

This information also has a significant impact on R&D. Currently, we oversize some product components on purpose. By knowing how the lift motor is actually used in the field [...], we can make smarter decisions about product components." (Director of Sales, Region A, OEM perspective)

Table 9 provides an overview of the four organizational affordances perceived by the OEM organization in our case context.

Table 9. Organizational affordances of OEMs

Organizational goal(s) *(code frequency)*		
Engineer safe, superior industrial products for a competitive price *(25)*		
Offer product-complementing services *(48)*		
ID	**Organizational affordance**	**Exemplary required organizational resources**
OEM #01	Product mix *(117)*	Knowledge about product usage to interpret data *(15)*
OEM #02	Product usage insights *(45)*	Industry-specific engineering capabilities *(13)*
		Knowledge about product usage to interpret data *(15)*
OEM #03	Identify product misuse *(36)*	Ability to interpret operational product usage data *(23)*
OEM #04	Product-complementing services *(72)*	Knowledge about customer needs *(22)*
		Sales channel to offer services to external actors *(7)*

First, digitized products that afford OEMs' product mix can be tailored to the needs of the PO (OEM #02).

We offer to optimize the product mix for the customer organization considering the tasks that need to be accomplished with our products. (Managing Director, Product Marketing and Communication, OEM perspective)

Second, digitized products afford the ability to gain insights into actual product usage.

It would be valuable for us to have a platform where we have this transparency to see the capacity use of all of our machines. (Head of Logistics and Process Performance, OEM perspective)

OEMs leverage those insights to engineer higher-value products (e.g., more energy efficiency, more durability) (OEM #01).

If we know exactly how my products were used and where issues occur, then we can improve future products or design upgrade kits to fix existing products. (Managing Director, Product Marketing and Communication, OEM perspective)

Third, digitized products afford "Identify product misuse" (OEM #03), which ensures fair warranty policies and contributes to the goal of offering superior products at competitive prices.

What are the environmental conditions of our products? Temperature? Dustiness and degree of air pollution? Because we want to earn more money from our customers in a fair way, we have to measure the environmental factors of product operations." (Managing Director, Innovation Management, OEM perspective)

Fourth, OEMs increasingly focus on service offerings that complement products, such as consulting services on proper product use and seizing of the installed base (OEM #04).

Based on a cross-functional innovation initiative, our goal is to offer entirely new services. [...] Today we can barely imagine the potential of our products when they are augmented with digital technology. (Director, Industrial Services, OEM perspective)

MRO perspective. The overall goal for MRO organizations is to ensure error-free, efficient, effective operations of industrial products. This goal can be measured by increasing the first-time-fix-rate (FTFR) and reducing follow-ups for service incidents.

For us, it all boils down to equipment productivity. Our principle is: "We take care of their equipment so operators can focus on their core business." (Head of MRO Services, MRO organization perspective)

That means we need to improve the first-time-fix-rate." (Director, Service Marketing, MRO perspective)

Table 10 on the following page provides an overview of the five organizational affordances perceived by the MRO role in our case context.

First, "Condition monitoring" allows MRO organizations to know the health status of digitized products (MRO #01). Knowing the condition of digitized products provides the foundation for other organizational affordances. Second, digitized products afford MRO organizations' "Triggering MRO activities" (MRO #02). Existing MRO processes do not have to be adjusted, although the ratio between planned and unplanned activities improves, resulting in higher operational efficiency as an immediate concrete outcome.

Table 10. Organizational affordances of MROs

Organizational goal(s) *(code frequency)*		
Ensure error-free operations of industrial products in an efficient and effective way *(98)*		
ID	**Organizational affordance**	**Exemplary required organizational resources**
MRO #01	Condition monitoring *(35)*	Context-specific knowledge on product operations *(10)*
MRO #02	Triggering MRO activities *(31)*	Dynamic scheduling of field service activities and technicians *(11)*
		Product failure prediction algorithms *(15)*
MRO #03	Empowering & optimizing field service activities *(93)*	Integration of mobile work support systems of blue-collar workers *(23)*
MRO #04	Remote online diagnosis *(31)*	Individuals or algorithms that are able to do remotely diagnose and solve problems *(32)*
MRO #05	Manage product operations and guarantee product uptime *(32)*	In-depth knowledge on product operations *(13)*

By integrating advanced analytical capabilities, MROs' activities can be anticipated before actual breakdowns happen, resulting in fewer downtimes and better service quality for the PO. In addition to leveraging data regarding the wear and tear of industrial products, fluctuations in product usage can be used as input data to trigger field service activities to occur when products are not used.

The goal of predictive maintenance is to predict when a component will break down and then replace it during a regular service interval, such as during the night, before a failure happens, so we can increase the overall availability of the product. (Vice President, Field Service, MRO perspective)

Third, digitized products afford the MRO activities of "Empowering and optimizing field service activities" (MRO #03). For instance, field service technicians can be provided with dedicated product data that help them fix the product. Another example is more effective spare parts management, as information on (potentially) broken parts is available before a service technician visits. Therefore, field service technicians must be equipped with mobile devices, and insights must be fed into mobile work support systems.

Currently, all technicians have a mobile device […] to manage and control their work. […] We need information on these devices from each product instance — real-time information, historical information, fault logs, […]." (Vice President, Service Support, MRO perspective)

Fourth, the frequency of field visits can be reduced by diagnosing products remotely and online (MRO #04).

There is an organizational function that focuses on diagnosing and resolving problems remotely to replace field visits, or if the field service agent is not able to solve it, he or a smart algorithm finds the cause of the problem and recommends a potential solution." (Director, Field Service and MRO, MRO perspective)

Fifth, MRO organizations might take over responsibility for fault-free product operations and guarantee product uptimes (MRO# 04).

The customer at a certain point of time says, "Okay, you take care of it. I just want my truck to run, to work properly, and to have no down time, and that's fine. (Director, Sales Region A, MRO perspective)

We want to sell service contracts that say that we take care of the customer's machine so the customer can focus on his core business. (Head of MRO Service, MRO perspective)

Product operator (PO) perspective. In this study, we consider the PO as the beneficiary actor within our archetypical service ecosystem. POs seek to integrate industrial products into their value co-creation without minimal effort and to gain operational transparency on value co-co-creation by drawing on digitized products. Table 11 provides an overview of the two organizational affordances perceived by the PO role in our case context.

Table 11. Organizational affordances of POs

Organizational goal(s) *(code frequency)*		
Integrate industrial products in own value-co-creation *(45)*		
Gain operational transparency on value co-creation processes that draw on digitized products *(54)*		
ID	**Organizational affordance**	**Exemplary required organizational resources**
PO #01	Gaining transparency on internal processes to manage work orders based on actual capacity *(65)*	Contextual data on product operations *(15)*
		Connectivity to existing legacy IT-systems such as ERP or CRM *(8)*
PO #02	Providing transparency on operations and processing of orders to customers *(48)*	Customer-facing system to communicate data *(25)*

Based on the organizational goals mentioned above, we can identify the following organizational affordances. The first of POs' organizational affordances has to do with their lack of operational transparency in their shop-floor activities. Digitized products afford POs' "gaining transparency on internal processes to manage work orders based on actual capacity" (PO #01).

"It would be valuable for us to have timely machine data, which would allow the foreman to see the status of work orders, such as the current processing speed, estimated time of completion of the work order, and disruptions in our production processes. We

leverage product data to derive our output and performance, Conclusions about product use would also be great. (Director of Operations, PO perspective)

Therefore, data from digitized products must be enriched by the contextual information that is necessary to interpret operational product data in the actual operational context.

Besides asset data, contextual information like "What are the workers doing?" or "Why are the machines not [operating] right now?" is needed." (Senior Manager, Maintenance and Facility Engineering, PO perspective)

However, contextual data is often siloed in proprietary systems. This information should be made available to other actors in the service ecosystem.

We have an antiquated ERP system that's more of an inventory system. [...] We feed some operational data on equipment operations into that system. Pairing some of that data with the data from the equipment would help us see the whole picture of what has occurred on that equipment over time. (Vice President, Operations, Region B, PO perspective)

Second, POs can leverage operational data to provide operational transparency to their customers (PO #02).

We can use the new data to provide our customers with more transparency and information about the state of their orders. (Head of Logistics and Process Management, PO perspective)

To increase operational transparency, POs need to establish customer-facing IT systems that allow them to exchange data with their customers.

Ecosystem perspective and collective affordances

Finally, our data indicates that shared and organizational affordances can be concatenated, resulting in collective affordances.

Observation 4: *In service ecosystems, organizational actors concatenate organizational affordances and integrate resources, resulting in smart service systems. Drawing on the affordance lens, we conceptualize such affordances as collective affordances that are collectively created by actors in the service ecosystem.*

As each actor specializes in a unique set of resources, actors are forced to intensify value co-creation and forge partnerships with other actors in the service ecosystem. Digitized products can act as a shared technology and service platform in the emerging smart service system.

We have to cooperate with external partners in terms of data analysis and frameworks and realizing entirely new service offerings. (Head of R&D Electrical Engineering and Automation, OEM perspective)

We consider this an ecosystem with multiple organizational actors that are all working on the same challenge. I believe that organizational borders are blurred. (Service Product Manager, Out of the Box Analytics, AO perspective)

Emerging smart service systems are often seen as complex in nature and as requiring an integration of resources that go beyond organizational resources.

We are constantly in search of smart, innovative services, but this is a little more complicated than developing new products or increasing the internal efficiency of technical customer service. (Managing Director of Product Marketing and Communication, OEM perspective)

Figure 3 presents a schematic overview of how smart service systems emerge based on evolutionary, shared, organizational, and collective affordances.

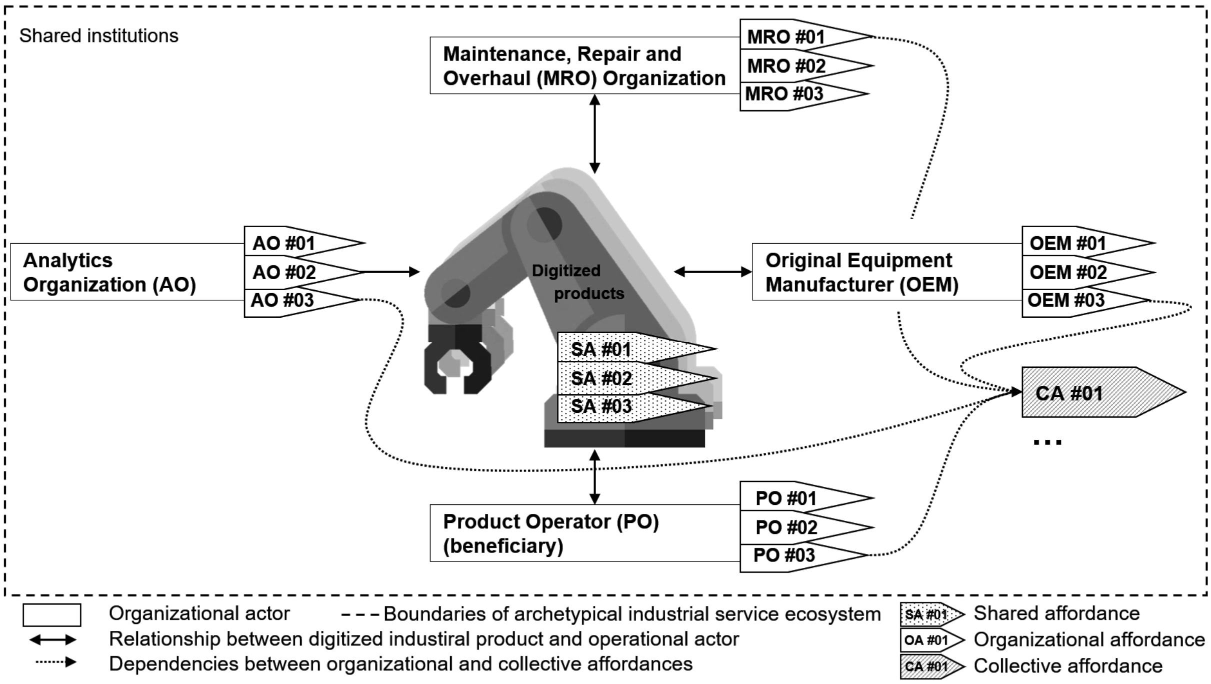


Figure 3. Emergence of smart service systems in the context of industrial service ecosystems

Value is always uniquely and phenomenologically determined by the beneficiary (Vargo and Lusch 2016), so shared goals that can maximize the value that the beneficiary perceives are the foundation of value co-creation within a service ecosystem. In our case context, actors are committed to enabling value co-creation by means of seamless integration of digitized industrial products.

Our data confirms that shared institutions must be in place in order to coordinate resource integration and service exchange (Barrett et al. 2015; Edvardsson et al. 2014; Lusch and Nambisan 2015; Vargo and Lusch 2016). Table 12 states the collective goal and provides an overview of the identified shared institutions within the service ecosystem.

Table 12. Collective goal and shared institutions in service ecosystem

(1) Collective goal: Enabling value co-creation by seamless integration of digitized industrial products *(12)*		
(2) Identified shared institutions *(code frequency)*		
	Shared institution	**Exemplary empirical evidence**
Technical	Open and standardized interfaces between digitized products and actors *(58)*	*[…] partners have to agree on which protocol they want to set. […] We currently neither have a standardization on the sensors nor we have a standardization on the CAN Bus nor we have a standardization on the data that we receive.* (Director, New Business and Product Digitization, OEM perspective)
Non-technical	Inter-actor partnerships and rules of participation *(135)*	*In the future, we won't have winners and losers anymore but we must form partnerships and collaborate with partners in a transparent and open manner in order to integrate [..] complementary resources.* (Director, Industrial Services, OEM perspective)
Non-technical	Data exchange, security and ownership agreement *(71)*	*And if we decide to exchange information with our customers, we have to ensure that this information is only used for the intended purpose. (Head of Product Marketing, OEM perspective)* *This brings us to the question: Who owns the data? Do we own them? Our customers or partners?* (Director, Industrial Services, OEM perspective)
Non-technical	Shared cognition, joint sense-making, similar understanding of value (41)	*Our own organization and organizations that we partner with must share this vision [of co-creating value for the beneficiary]. Besides, partner organizations must also perceive value for themselves and a pioneer in the market.* (Head of Global Software Development, OEM perspective)
Non-technical	Trust and loyalty among actors involved in value co-creation *(21)*	*It is no longer enough to just trust the OEM – what we do as we were customers for many years. We also have to trust Analytics Organizations regarding that data we hand over to them with regard to competitors that might also be customers of that organization.* (Head of Internet of Things and Operations, PO perspective)
Non-technical	Ability to jointly work on innovative smart service systems *(16)*	*We created innovation garage – a program where interdisciplinary teams work on early ideas apply agile development methods to build innovative digital business models based on digitization of our products.* (Group Chief Technology Officer and Head of Group R&D, OEM perspective)

Given the shared goals and shared institutions, the integration of complementary organizational resources results in smart service systems that could not be generated by individual actors alone. Table 13 provides an overview of the collective affordances identified and names an exemplary set of organizational resources for each collective affordance.

Table 13. Identified collective affordances with exemplary, required organizational resources

ID	Collective affordance *(code frequency)*	Exemplary required organizational resources
CA #01	Managing and -optimizing product operations *(27)*	**OEM:** Industry- and product-specific knowledge to leverage operational product data in the industrial service business
		MRO: Knowledge and experience on product operations, spare parts logistics, efficient field operations
		AO: Condition monitoring, event triggering
		PO: Context and need that allows value co-creation with digitized products, information on internal processes, open and standardized interfaces to existing information systems
CA #02	Performance-based contracting *(32)*	**OEM:** On-demand billing, strong relationship with PO
		MRO: Service history, technical knowledge on product operations
		AO: Link between historic operational product usage data and price drivers
		PO: Access to operational product data
CA #03	Managing product operator's processes *(27)*	**OEM:** Trust and long-term relationship between OEM and PO
		MRO: Efficient field operations, anticipating needs of POs
		AO: Expertise in dealing with vast amounts of operational product data, timely, reliable, and secure collection and analysis of operational product data, expertise in artificial intelligence and machine learning, sufficiently large data set to train algorithms
		PO: Knowledge on operational processes

Here, we describe the collective affordances that emerged in our archetypical service ecosystem.

Managing and -optimizing product operations (CA #01). Digitized products afford industrial actors ability to manage and optimize product operations (CA #01).

The customer will be able to be more effective with less equipment because of products' increased uptime. Digital solutions like wearing sensors, as well as localization, will help to increase the product's efficiency and lower the number of machines needed (Director of Industrial Services, OEM perspective)

This means providing the customer a superior and understanding service beyond maintenance and repair of an (almost) broken machine. Thus, we also offer operational optimization, training, proper design of the machine's productive environment, and safety systems with operational warnings to manage and optimize product operations comprehensively. (Director, Service Standards, OEM perspective)

The affordance addresses the collective goal of seamless integration of digitized products into value co-creation with the beneficiary. To implement the collective affordance, organizational resources are required that are stated in Table 13.

Performance-based contracting (CA #02). Performance-based contracting (CA #02) focuses on charging the PO depending on actual use of industrial products.

Our customers are no longer interested in placing machines on their shop floors and paying a fixed monthly subscription rate. […] The flexible pricing topic has a tremendous number of subtopics and dependencies that need to be in place. Some of them can be implemented easily and allow us to generate added value on our way to this beast [topic]. (Managing Director of Technology and Innovation Management, OEM perspective)

The collective affordance consists of a set of shared and organizational affordances that should be in place. The smart reconfiguration of those affordances within a smart service system results in performance-based contracting.

Offering flexible pricing models and selling products as services require a high degree of interdisciplinary collaboration: we need digitization experts, IT experts, sales guys, controllers, and marketing people to work closely together. It also involves in-depth research with key customers, and key account managers." (Managing Director, Innovation Management, OEM perspective)

Partnering allows us to offer performance contracting, resulting in an attractive price model for the customer […] that includes service activities […], as he does not have to take any risks. […] I believe it all boils down to added value for the customer. (Service Line Manager, Energy Data Management & Head of Analytics Service Development, AO perspective)

If the customer experiences a drop in orders or uses our products less, he pays less. (Managing Director of Technology, OEM perspective)

Managing product operator's processes (CA #03). Finally, our data indicates that emerging smart service systems can even go beyond the seamless integration of digitized industrial products, not only managing and optimizing product operations (CA #01) or billing digitized products based on their actual performance (CA #02) but even immersing into value co-creation with the beneficiary.

[Customers] expect that such offerings take a great amount of work to manage not only our equipment during the operations phase but also the processes related to them. Doing this for them allows customer to focus on their core competencies […]. (Managing Director, Product Marketing and Communication, OEM perspective)

I believe that it is all about processing as much operational information as possible to address the customer's needs in a comprehensive and proactive way. (Head of Business Development, MRO perspective)

Discussion and implications

Now that we have outlined how our results are rooted in empirical data obtained from an archetypical industrial service ecosystem, we can discuss the theoretical and managerial implications regarding our initial research question: *How do digitized products afford service innovation in industrial service ecosystems?*

Theoretical implications

In discussing the theoretical implications of how smart service systems evolve, we adopt the tripartite service innovation framework, with its dimensions of service platform, service ecosystem, and value co-creation (Lusch and Nambisan 2015).

Service platform. Findings from our archetypical industrial service ecosystem indicate that actors draw on a fixed set of digitized products' material properties (Observation 1). Based on this shared technological foundation, digitized products enable affordances that are context-independent and shared among organizational actors (Observation 2). The multitude of affordances raises the question concerning how digitized products should be designed in a generative way to enable these affordances. Loosely coupled structures and the layered modular architecture might be valuable concepts when digitized products and services are designed (reference blinded for review). Picking up on existing work, this study also finds that affordances transcend organizational boundaries as they spark smart service systems. Therefore, future research should focus on affordance-based design of digitized products (Maier and Fadel 2008), community-based generativity and distributed service innovation (Nambisan et al. 2016), and interdisciplinary engineering methodologies to engineer effective smart service systems (Böhmann et al. 2014; Breidbach and Maglio 2016; Peters et al. 2016).

In addition, shared institutions must be in place to allow actors to co-create value in smart service systems. Open and standardized interfaces between the individual components of digitized products and actors are examples of technological shared institutions. We also find that the digital products' materiality allows these technological shared institutions to be modified after manufacturing a product based on the requirements of an emerging smart service system. For instance, the velocity of sensor data can be increased if a new smart service system needs more timely data. Our case also reveals that non-technical shared institutions provide an important foundation for smart service systems as an additional part of service platforms. Existing work observes that shared institutions are often under-recognized or even ignored in investigations of service innovation (Barrett et al. 2015), yet such work highlights their importance in service systems (Edvardsson et al. 2014; Wieland et al. 2016). While focusing on organizational affordances, we find that efficiency and quality improvements in existing services can be accomplished without shared institutions (Observation 3). However, service ecosystems require establishing shared institutions early on in order to foster resource liquefaction, resource density, and resource integration so actors can align organizational affordances with potential smart service systems and co-creation of value within the service ecosystem. Existing research refers to such alignment as *institutional work* (Vargo et al. 2015; Wieland et al. 2016).

Service ecosystem. The proper configuration of organizational actors in the service ecosystem is a key foundation for smart service systems. Our archetypical case service ecosystem is characterized by actors with complementary resources but shared digital technology and shared institutions that enable these actors to integrate their resources into the system. Similarly, Leonardi (2013) finds that collective affordances arise when individual actors are highly specialized at an individual-actor level. Because of actors' specialization, we identify affordance dependencies between arising affordances. Although affordance dependencies and differentiation between basic and thematic affordances are not new concepts (Strong et al. 2014; Volkoff and Strong 2013), this study identifies systematic dependencies between shared, organizational, and collective affordances as three classes of affordances, thus going beyond existing work that focuses only on the identification of individual affordances. For instance, "Condition monitoring" (SA #01), an example of a shared affordance, must be in place as a foundation for "Empowering and optimizing field service activities" (MRO #03). Likewise, it affords the OEM the ability to identify product misuse (OEM#03) and offer services that complement products (OEM #04). Finally, the shared and organizational affordances together, an example of a collective affordance provide the foundation for "Performance-based contracting" (CA #02) as a smart service system that involves multiple actors in the service ecosystem. Shared technical institutions, such as open and standardized interfaces, as well as service modularization, mitigate these dependencies (Tuunanen and Cassab 2011). Further research is needed to determine the role of non-technical shared institutions and service platforms in dependencies.

Value co-creation. This study contributes to clarifying how digitized products are leveraged to co-create value at both an organizational and an ecosystem level. In particular, the reconfiguration of service ecosystems to co-create value effectively in smart service systems is a relevant aspect for further research in the interconnected and digital age.

With the rise of digitized products, the role of digital technology shifts toward that of an operant resource. We find that organizational actors leverage digitized products as operant resources in organizational affordances that are contingent on organizational goals and context (Observation 3). We can also conclude from our case data that organizational affordances usually improve the efficiency and quality of existing service offerings incrementally, and find that these organizational affordances are the foundation for collective affordances that emerge between actors within the service ecosystem (Observation 4) and spark new modes of value co-creation in realizing smart service systems. Arthur (2009) frames this cascading nature of service innovation as the "combinatorial evolution" of value propositions based on digital technology. Our results indicate that the evolution of smart service systems in industrial service ecosystems are stepwise in nature. We distinguish among *shared*, *organizational*, and *collective* affordances by drawing on Leonardi's (2013) three foundational concepts. First, actor-independent shared affordances like "Monitoring product condition" (SA #01) are closely tied to digitized products' material properties, so they are perceived by various actors. Second, actors perceive organizational affordances that address their respective organizational goals and organizational contexts. Those affordances draw on shared affordances and organizational resources as a foundation. Organizational affordances like "Triggering MRO activities" (MRO #02), "Empowering and optimizing field service activities" (MRO #03), and "Remote online diagnosis" (MRO #04) all result in increased internal operational efficiency. "Product usage insights" (OEM #02) addresses internal goals and aims at quality improvements of physical products to increase service quality and effectiveness. Finally, our case study shows that collective affordances spark smart service systems to create entirely new value propositions such that additional actors become involved in value co-creation, and the beneficiaries' needs are increasingly considered. Our case identifies "Managing and optimizing product operations" (CA #01), "Performance-based contracting" (CA #02), and "Managing POs' processes" (CA #03) as collective affordances. The stepwise and evolutionary nature of service innovation based on digitized products is in line with existing research on service innovation and the reverse product cycle model (Barras 1986; Barrett et al. 2015). The stepwise evolution of shared, organizational, and collective affordances serves as a conceptual foundation for further research on the collaborative recombination — or "combinatorial evolution" — of practices that provide novel solution to problems (Arthur 2009; Vargo et al. 2015).

Managerial implications

For practitioners in the manufacturing industry, this paper provides four primary insights into decisions regarding how to harness digitized products effectively.

First, digitized products are the foundation of smart service offerings of any kind, but the long product lifecycles make it challenging to establish digitized products' physical materiality (i.e., device layer, network layer), a vital foundation for service innovation. OEMs are obliged to make ex-ante decisions on important parts of the technological foundation, so during engineering and design of digitized products, they must have at least a rough idea about the potential requirements that stem from the smart service system. Interdisciplinary proof-of-concept projects (reference blinded for review) and the taxonomies of smart service systems (reference blinded for review) might help OEMs to get a feeling for the solution space. Furthermore, a service platform that follows the principles of the layered modular architecture facilitates integration of the OEM's resources with those of other actors and the emergence of smart service systems. Because of the importance of design decisions regarding digitized products on the emergence of smart service systems, product engineers should work closely with those who are in charge of service systems engineering. Interdisciplinary workshops and collaboration may be helpful ways to foster fruitful interactions for both sides.

Second, our work indicates that smart service systems in industrial manufacturing are developed in a stepwise manner. We observe that organizations initially focus on organizational affordances, but in the end, value is co-created in smart service systems that emerge based on collective affordances. Therefore, instead of running behind organizational affordances that are often just hyped topics, organizations should identify the needs related to the beneficiary's work in order to develop adequate value proposition within emerging smart service systems. Although they provide the foundation for smart service systems, organizational affordances should be considered quick wins (e.g., gains in the efficiency or quality of existing service offerings) that can help to justify expenses along the stepwise journey toward developing collective affordances and value co-creation in smart service systems.

Third, the development of shared affordances faces the threat of commoditization, as many shared affordances do not require actor-specific resources. Therefore, to ensure their continued role in value co-creation, actors that are involved in actualizing shared affordances should build or leverage platforms with the goal of offering more advanced, data-driven services. Organizations that focus on collective affordances and contributing to value co-creation in smart service systems must identify their unique value propositions in the ecosystem, as collective affordances exist only once: only one actor can integrate needed resources with those of other actors and participate in value co-creation with them. Therefore, organizations in the service ecosystem race against each other to participate in value co-creation with respect to shared and collective affordances. Developing adequate organizational affordances allows actors to participate in integrating their resources with those they want in smart service systems.

Finally, smart service systems change how value is co-created in the industrial service business. In traditional service ecosystems, actors might have opposing organizational goals. For instance, OEMs might sell lower-quality products to stay competitive, exceed the delta in revenue with additional MRO activities that are characterized by higher margins, or charge POs for their own inefficiencies when it charges for multiple visits of skilled service technicians to diagnose the cause of a breakdown, install spare parts, and finally fix it. Our investigations at the organizational and ecosystem level reveal that smart service systems reduce mismanagement in the industrial service business.

Limitations and further research

Drawing on a revelatory case study and forty-seven semi-structured interviews with managers in the industrial service business, this study explores how the generative capacity of digitized products affords smart service systems in the context of the industrial service business. We find that actors in our service ecosystem draw on a fixed set of digitized products' material properties as a foundation for *shared*, *organizational,* and *collective* affordances as stepwise elements toward smart service systems. Specifically, we find that the evolution of shared and organizational affordances through combination and recombination results in collective affordances that spark smart service systems to serve beneficiaries' needs.

These results should be viewed in light of two primary limitations. First, the study's unit of analysis is an archetypical service ecosystem in the context of industrial manufacturing. Although we selected the configuration based on our investigation's requirements, actual actor configuration in industrial manufacturing might differ from the study's exemplary setting. Other affordances could arise in other organizational settings or industries. Second, a different team of researchers might interpret the codes we identified and the affordances derived differently than we did, although we sought to develop a clear chain of evidence by considering multiple data sources and to establish reasonable interrater agreement in coding of the data. Nonetheless, we suggest conducting additional studies in a similar context to corroborate our findings.

Despite those limitations, our explorative findings serve as a foundation for further research on the evolution of smart service systems in the interdisciplinary context of industrial manufacturing. By leveraging and extending affordance theory, this work illuminates the stepwise emergence of smart service systems in industrial manufacturing. Future work should abstract from single ecosystems and investigate how service innovation is accomplished systematically (Maglio and Breidbach 2014). One approach to this effort could be to identify generic resource integration patterns (Storbacka et al. 2016). This work also lays the foundation for future research on the combined dependencies of the shared, organizational, and collective affordances we identified.

Acknowledgements

This work has been supported by the *Swiss National Science Foundation (SNSF).* We furthermore would like to thank the project partners and member organizations of the *Competence Center Industrial Services and Enterprise Systems (CC ISES)* at the *Institute for Information Management (IWI-HSG)* at *University of St.Gallen* and Oliver Marti, who supported this research project in an early stage in the course of his master's thesis.

Appendix

Table A 1. Overview of collected and analyzed empirical data among archetypical actors in the industrial service ecosystem

Org. Actor	Data source	General information	Detailed information	Duration
Analytics Organization (AO) perspective	Semi-structured interviews	7 interviews ∑ 10:30h -μ: 1:30h -σ: 21:03min 152 pages of text	Service Line Manager, Plant Cloud Services Service Product Manager, Out of the Box Analytics Head of Managed Service/ Analytics Head of Analytical Service Development Service Line Manager, Asset Analytics Services Service Line Manager, Process Data Analytics Service Line Manager, Energy Data Management	85 min 96 min 131 min 96 min 73 min 67 min 82 min
	Focus group workshops and meetings	Full-day	Full-day workshop (FDWS) to elicit potential business models	Full day
	Internal documents and archival data	Business concept and strategic presentations	Internal documents and strategic presentations on business concept to provide data-driven services in industrial manufacturing	-
Original Equipment Manufacturer (OEM) perspective	Semi-structured interviews	15 interviews -∑ 15:56h -μ: 1:04h -σ: 20:12min 267 pages of text	Group Chief Technology Officer and Head of Group R&D Managing Director, Innovation Management Head of IT-Architecture, Standards, and Innovation Managing Director, Product Marketing & Communication Head of Digital Business Development Director, Industrial Services Technical Lead Product Digitization Head of Competence Center IoT Platform Architecture Director, New Business and Product Digitization Managing Director, Technology Director, Sales Region A Head of Global Software Development Global Head of IT Operations Head of Product Marketing Head of R&D Electrical Engineering and Automation	51 min 40 min 46 min 84 min 52 min 91 min 22 min 83 min 63 min 84 min 83 min 64min 64 min 49 min 80 min
	Focus group workshops and meetings	4 full-day workshops and 2 meetings	Digitized equipment 2.0 proof-of-concept kickoff FDWS Milestone review workshop I Milestone review workshop II Smart service systems innovation workshop 6 1-hour 1:1 meetings on smart service scenarios Foresight workshop on flexible pricing models and outcome-based offerings	Full day Full day Full day Full day 6 hours 2 hours
	Internal documents and archival data	Strategic service innovation concepts, technical documentations	Presentation on strategic service innovation clusters; 2x innovation board status presentations: project brief on business model transformation project (usage-based industrial equipment offerings and servitization), Internet of Things/telematics platform architecture proposal, sensor data payload calculations, target data model: operational industrial product data, network and connectivity requirements documentation	-
Maintenance, Repair and Overhaul	Semi-structured interviews	15 interviews -∑ 17:10h -μ: 1:09h -σ: 21:12min 279 pages of text	Director, Service Operations Director, After-Sales Service Region A Director, Technical Customer Service Head of MRO Service Executive Director Service Director, After-Sales and Customer Service	74 min 78 min 75 min 36 min 40 min 108 min

			Head of Business Development Head of Full Service Business Vice President, Service Support Manager, Business Dev. & Digital Transformation Head of Technical Service Vice President, Field Service Head of Industrial Service Director, Field Service and MRO Director, Service Standards	38 min 53 min 63 min 54 min 96 min 83 min 75 min 85 min 72 min
	Focus group workshops and meetings	1 full-day service design thinking workshops and 7 smart service scenario identification sessions	One-day service innovation and digitization workshop leveraging elements from the design thinking methodology, 7 smart service scenario expert session with the goal to brainstorm potential smart service scenarios and use/revenue potentials for harnessing digitized products in the context of the industrial MRO business	Full day 7 a 60 mins
	Internal documents and archival data	Strategic service innovation concepts, technical documentations	Strategic documents on innovation in the context of MRO and service business	-
Product operator (PO) perspective	Semi-structured interviews	10 interviews - ∑ 11:46h - μ: 1:11h - σ: 11:46min 157 pages of text	Head of E-Commerce and Digitization Senior Manager, Maintenance and Facility Engineering Head of Internet of Things and Operations Manager, Organizational Design, Processes & Change Head of Logistics and Process Performance Vice President, Operations Region A Vice President, Operations Region B Director Operations Vice President, Technology and Equipment Vice President, Business Development and Operational Excellence	80 min 82 min 59 min 69 min 74 min 64 min 59 min 54 min 74 min 91 min
	Focus group workshops and meetings	2 full-day workshops and 34 status calls	Two full-day workshops with interdisciplinary staff ranging from management to blue-collar positions (shift supervisor) to identify use potentials of digitizing existing proprietary installed base to optimize productivity/uptime of products and optimize internal processes and various status calls in implementation status	2x full day
	Internal documents and archival data	Operational process models and documentations, emails	Process documentations, internal documents on digitization potentials and strategic decisions in running and planned digitized initiatives, emails and documents exchanged between digitization consultants and internal management	-

References

Accenture, and General Electric Company 2015. *Industrial Internet Insights Report*.

Akaka, M. A., and Vargo, S. L. 2013. "Technology as an Operant Resource in Service (Eco)Systems," *Information Systems and e-Business Management* (12:3), pp. 367–384.

Allmendinger, G., and Lombreglia, R. 2005. "Four Strategies for the Age of Smart Services," *Harvard Business Review* (83:10), p. 131.

Anderson, C., and Robey, D. 2017. "Affordance Potency: Explaining the Actualization of Technology Affordances," *Information and Organization* (27:2), pp. 100–115.

Annunziata, M., and Evans, P. C. 2012. *Industrial Internet: Pushing the Boundaries of Minds and Machines*, General Electric Company.

Arthur, W. B. 2009. *The Nature of Technology: What It Is and How It Evolves*, New York, NY: Simon and Schuster.

Avital, M., and Te'eni, D. 2009. "From Generative Fit to Generative Capacity: Exploring an Emerging Dimension of Information Systems Design and Task Performance," *Information Systems Journal* (19:4), pp. 345–367.

Baines, T., and Lightfoot, H. 2013. *Made to Serve: How Manufacturers Can Compete Through Servitization and Product Service Systems*, Chichester, West Sussex, United Kingdom: Wiley.

Bardhan, I. R., Demirkan, H., Kannan, P. K., Kauffman, R. J., and Sougstad, R. 2010. "An Interdisciplinary Perspective on IT Services Management and Service Science," *Journal of Management Information Systems* (26:4), pp. 13–64.

Barras, R. 1986. "Towards a Theory of Innovation in Services," *Research Policy* (15:4), pp. 161–173.

Barrett, M., Davidson, E., Prabhu, J., and Vargo, S. L. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Quarterly* (39:1), pp. 135–154.

Becker, J., Beverungen, D., Knackstedt, R., Matzner, M., Muller, O., and Poppelbuss, J. 2013. "Bridging the Gap Between Manufacturing and Service Through IT-Based Boundary Objects," *IEEE Transactions on Engineering Management* (60:3), pp. 468–482.

Beirão, G., Patrício, L., and Fisk, R. P. 2017. "Value Cocreation in Service Ecosystems: Investigating Health Care at the Micro, Meso, and Macro Levels," *Journal of Service Management* (28:2), pp. 227–249.

Berente, N., Lyytinen, K., Yoo, Y., and King, J. L. 2016. "Routines as Shock Absorbers During Organizational Transformation: Integration, Control, and NASA's Enterprise Information System," *Organization Science* (27:3), pp. 551–572.

Beverungen, D. 2011. "Mapping the Emerging Field of Service Science: Insights from a Citation Network and Cocitation Network Analysis," in *Proceedings of the 32nd International Conference on Information Systems (ICIS)*, Shanghai, China.

Blinn, N., and Nüttgens, M. 2010. "Empowering Technical Customer Services with Intelligent Mobile Applications: A Contingency Theory-Based Approach," *All Sprouts Content* (399).

Böhmann, T., Leimeister, J. M., and Möslein, K. 2014. "Service Systems Engineering: A Field for Future Information Systems Research," *Business & Information Systems Engineering* (6:1), pp. 73–79.

Breidbach, C. F., and Maglio, P. P. 2016. "Technology-Enabled Value Co-Creation: An Empirical Analysis of Actors, Resources, and Practices," *Industrial Marketing Management* (56), pp. 73–85.

Brocke, J. vom, Zelt, S., and Schmiedel, T. 2016. "On the Role of Context in Business Process Management," *International Journal of Information Management* (36:3), pp. 486–495.

Bryman, A., and Bell, E. 2015. *Business Research Methods*, Oxford: Oxford University Press.

Chandler, J. D., and Vargo, S. L. 2011. "Contextualization and Value-in-Context: How Context Frames Exchange," *Marketing Theory* (11:1), pp. 35–49.

Corbin, J., and Strauss, A. 2008. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, Thousand Oaks, CA: Sage Publications.

Corbin, J., and Strauss, A. 1990. "Grounded Theory Research: Procedures, Canons, and Evaluative Criteria," *Qualitative Sociology* (13:1), pp. 3–21.

Easterby-Smith, M., Thorpe, R., and Jackson, P. R. 2012. *Management Research*, Los Angeles, CA: Sage Publications.

Edvardsson, B., Kleinaltenkamp, M., Tronvoll, B., McHugh, P., and Windahl, C. 2014. "Institutional Logics Matter when Coordinating Resource Integration," *Marketing Theory* (14:3), pp. 291–309.

Edvardsson, B., Tronvoll, B., and Gruber, T. 2011. "Expanding Understanding of Service Exchange and Value Co-Creation: A Social Construction Approach," *Journal of the Academy of Marketing Science* (39:2), pp. 327–339.

Eggert, A., Hogreve, J., Ulaga, W., and Muenkhoff, E. 2011. "Industrial Services, Product Innovations, and Firm Profitability: A Multiple-Group Latent Growth Curve Analysis," *Industrial Marketing Management* (40:5), pp. 661–670.

Eggert, A., Hogreve, J., Ulaga, W., and Muenkhoff, E. 2014. "Revenue and Profit Implications of Industrial Service Strategies," *Journal of Service Research* (17:1), pp. 23–39.

Eisenhardt, K. M., and Graebner, M. E. 2007. "Theory Building from Cases: Opportunities and Challenges," *Academy of management journal* (50:1), pp. 25–32.

Eisenhardt, K. M. 1989. "Building Theories from Case Study Research," *Academy of Management Review* (14:4), pp. 532–550.

Fain, N., Wagner, B., and Kay, N. 2017. "Driving Innovation Through Ambidextrous Service Provision — Long Life Cycle Products in Manufacturing Contexts," *Technological Forecasting and Social Change*.

Fayard, A.-L., and Weeks, J. 2014. "Affordances for Practice," *Information and Organization* (24:4), pp. 236–249.

Fellmann, M., Hucke, S., Breitschwerdt, R., Thomas, O., Blinn, N., and Schlicker, M. 2011. "Supporting Technical Customer Services with Mobile Devices: Towards an Integrated Information System Architecture," in *Proceedings of the 17th American Conference on Information Systems (AMCIS)*, Detroit, USA.

Gebauer, H., Fleisch, E., and Friedli, T. 2005. "Overcoming the Service Paradox in Manufacturing Companies," *European Management Journal* (23:1), pp. 14–26.

Gebauer, H., Paiola, M., and Saccani, N. 2013. "Characterizing Service Networks for Moving from Products to Solutions," *Industrial Marketing Management* (42:1), pp. 31–46.

Gibson, J. J. 1986. *The Ecological Approach to Visual Perception*, London: Psychology Press.

Glaser, B. G., and Strauss, A. L. 2009. *The Discovery of Grounded Theory: Strategies for Qualitative Research*, New York: Transaction Publishers.

Grönroos, C., and Helle, P. 2010. "Adopting a Service Logic in Manufacturing: Conceptual Foundation and Metrics for Mutual Value Creation," *Journal of Service Management* (21:5), pp. 564–590.

Grönroos, C. 2008. "Service logic revisited: who creates value? And who co-creates?," *European Business Review* (20:4), G. Svensson (ed.), pp. 298–314.

Gummesson, E. 2008. "Extending the Service-Dominant Logic: From Customer Centricity to Balanced Centricity," *Journal of the Academy of Marketing Science* (36:1), pp. 15–17.

Halinen, A., and Törnroos, J.-Å. 2005. "Using Case Methods in the Study of Contemporary Business Networks," *Journal of Business Research* (58:9), pp. 1285–1297.

Kindström, D., Kowalkowski, C., and Sandberg, E. 2013. "Enabling Service Innovation: A Dynamic Capabilities Approach," *Journal of Business Research* (66:8), pp. 1063–1073.

Kindström, D., and Kowalkowski, C. 2009. "Development of Industrial Service Offerings: A Process Framework," *Journal of Service Management* (20:2), pp. 156–172.

Klein, H. K., and Myers, M. D. 1999. "A Set of Principles for Conducting and Evaluating Interpretive Field Studies in Information Systems," *MIS Quarterly* (23:1), pp. 67–93.

Landis, J. R., and Koch, G. G. 1977. "The Measurement of Observer Agreement for Categorical Data," *Biometrics* (33:1), pp. 159–174.

Lapointe, L., and Rivard, S. 2007. "A Triple Take on Information System Implementation," *Organization Science* (18:1), pp. 89–107.

Larivière, B., Bowen, D., Andreassen, T. W., Kunz, W., Sirianni, N. J., Voss, C., et al. 2017. "'Service Encounter 2.0': An investigation into the roles of technology, employees and customers," *Journal of Business Research* (79), pp. 238–246.

Leonardi, P. M., and Barley, S. R. 2008. "Materiality and Change: Challenges to Building Better Theory about Technology and Organizing," *Information and Organization* (18:3), pp. 159–176.

Leonardi, P. M. 2013. "When Does Technology Use Enable Network Change in Organizations? A Comparative Study of Feature Use and Shared Affordances," *MIS Quarterly* (37:3), pp. 749–775.

Leonardi, P. M. 2011. "When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies," *MIS Quarterly* (35:1), pp. 147–168.

Lerch, C., and Gotsch, M. 2015. "Digitalized Product-Service Systems in Manufacturing Firms," *Research Technology Management* (58:5), pp. 45–52.

Lightfoot, H., Baines, T., and Smart, P. 2013. "The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends," *International Journal of Operations & Production Management* (33:11–12), pp. 1408–1434.

Lusch, R. F., and Nambisan, S. 2015. "Service Innovation: A Service-Dominant (SD) Logic Perspective," *MIS Quarterly* (1:39), pp. 155–175.

Lusch, R. F., and Vargo, S. L. 2014. *Service-Dominant Logic: Premises, Perspectives, Possibilities*, Cambridge, England: Cambridge University Press.

Lyytinen, K., Yoo, Y., and Boland, R. J. 2015. "Digital Product Innovation within Four Classes of Innovation Networks," *Information Systems Journal* (26:1), pp. 47–75.

Maglio, P., Bailey, J., and Gruhl, D. 2007. "Steps Toward a Science of Service Systems," *Computer* (40:1), pp. 71–77.

Maglio, P., and Breidbach, C. F. 2014. "Service Science: Toward Systematic Service System Innovation," in *INFORMS Tutorials in Operations Research*, pp. 161–170.

Maglio, P., and Spohrer, J. 2008. "Fundamentals of Service Science," *Journal of the Academy of Marketing Science* (36:1), pp. 18–20.

Maglio, P. 2015. "Editorial—Smart Service Systems, Human-Centered Service Systems, and the Mission of Service Science," *Service Science* (7:2), pp. ii–iii.

Maier, J. R. A., and Fadel, G. M. 2008. "Affordance Based Design: A Relational Theory for Design," *Research in Engineering Design* (20:1), pp. 13–27.

Majchrzak, A., and Markus, M. L. 2013. "Technology Affordances and Constraints in Management Information Systems (MIS)," in *Encyclopedia of Management Theory*, E. Kessler (ed.), Thousand Oaks, CA: Sage Publications, pp. 832–836.

Markus, M. L., and Silver, M. S. 2008. “A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole’s Concepts of Structural Features and Spirit,” *Journal of the Association for Information Systems* (9:10), pp. 609–632.

Martín-Peña, M. L., Pinillos, M.-J., and Reyes, L.-E. 2017. “The Intellectual Basis of Servitization: A Bibliometric Analysis,” *Journal of Engineering and Technology Management* (43), pp. 83–97.

Mathieu, V. 2001. “Product Services: From a Service Supporting the Product to a Service Supporting the Client,” *Journal of Business & Industrial Marketing* (16:1), pp. 39–61.

Medina-Borja, A. 2015. “Editorial Column - Smart Things as Service Providers: A Call for Convergence of Disciplines to Build a Research Agenda for the Service Systems of the Future,” *Service Science* (7:1), pp. ii–v.

Meyer, G. G., Wortmann, J. c., and Szirbik, N. B. 2011. “Production Monitoring and Control with Intelligent Products,” *International Journal of Production Research* (49:5), pp. 1303–1317.

Miles, I. 2008. “Patterns of Innovation in Service Industries,” *IBM Systems Journal* (47:1), pp. 115–128.

Miles, M. B., and Huberman, A. M. 1994. *Qualitative Data Analysis: An Expanded Sourcebook*, Thousand Oaks, CA: Sage Publications.

Moore, G. C., and Benbasat, I. 1991. “Development of an Instrument to Measure the Perceptions of Adopting an Information Technology Innovation,” *Information Systems Research* (2:3), pp. 192–222.

Myers, M. D., and Newman, M. 2007. “The Qualitative Interview in IS Research: Examining the Craft,” *Information and Organization* (17:1), pp. 2–26.

Nambisan, S., Lyytinen, K., Majchrzak, A., and Song, M. 2016. “Digital Innovation Management: Reinventing Innovation Management Research in a Digital World,” *MIS Quarterly* (41:1), pp. 223–238.

Nambisan, S. 2013. “Information Technology and Product/Service Innovation: A Brief Assessment and Some Suggestions for Future Research,” *Journal of the Association for Information Systems* (14:4), pp. 215–226.

Neely, A. 2008. “Exploring the Financial Consequences of the Servitization of Manufacturing,” *Operations Management Research* (1:2), pp. 103–118.

Ng, I. C. L., Ding, D. X., and Yip, N. 2013. “Outcome-Based Contracts as new Business Model: The Role of Partnership and Value-Driven Relational Assets,” *Industrial Marketing Management* (42:5), pp. 730–743.

Orlikowski, W. J., and Lacono, C. S. 2001. “Desperately Seeking the ‘IT’ in IT Research - A Call to Theorizing the IT Artifact,” *Information Systems Research* (12:2), p. 121.

Orlikowski, W. J. 2007. “Sociomaterial Practices: Exploring Technology at Work,” *Organization Studies* (28:9), pp. 1435–1448.

Peters, C., Maglio, P., Badinelli, R., Harmon, R., Maull, R., Spohrer, J., et al. 2016. “Emerging Digital Frontiers for Service Innovation,” *Communications of the Association for Information Systems* (39:1).

Piccinini, E., Hanelt, A., Gregory, R., and Kolbe, L. 2015. “Transforming Industrial Business: The Impact of Digital Transformation on Automotive Organizations,” in *Proceedings of the 36th International Conference on Information System (ICIS)*, Fort Worth, TX.

Porter, M. E., and Heppelmann, J. E. 2015. “How Smart, Connected Products Are Transforming Companies,” *Harvard Business Review* (93:10), pp. 96–114.

Porter, M. E., and Heppelmann, J. E. 2014. “How Smart, Connected Products are Transforming Competition,” *Harvard Business Review* (92:11), pp. 64–86.

Pozzi, G., Pigni, F., and Vitari, C. 2014. “Affordance Theory in the IS Discipline: A Review and Synthesis of the Literature,” in *Proceedings of the 20th Americas Conference on Information Systems (AMCIS)*, Savannah, USA.

Rai, A., and Sambamurthy, V. 2006. “The Growth of Interest in Services Management: Opportunities for Information Systems Scholars,” *Information Systems Research* (17:4), pp. 327–331.

Robey, D., and Boudreau, M.-C. 1999. “Accounting for the Contradictory Organizational Consequences of Information Technology: Theoretical Directions and Methodological Implications,” *Information Systems Research* (10:2), pp. 167–185.

Rust, R. T., and Cooil, B. 1994. “Reliability Measures for Qualitative Data: Theory and Implications,” *Journal of Marketing Research* (31:1), pp. 1–14.

Sawhney, M., Wolcott, R. C., and Arroniz, I. 2006. “The 12 Different Ways for Companies to Innovate,” *Sloan Management Review* (47:3), pp. 28–34.

Seidel, S., Recker, J., and Vom Brocke, J. 2013. "Sensemaking and Sustainable Practicing: Functional Affordances of Information Systems in Green Transformations," *MIS Quarterly* (37:4), pp. 1275–1299.

Silverman, D. 2010. *Qualitative Research*, Thousand Oaks, CA: Sage Publications.

Storbacka, K., Brodie, R. J., Böhmann, T., Maglio, P. P., and Nenonen, S. 2016. "Actor Engagement as a Microfoundation for Value Co-Creation," *Journal of Business Research* (69:8), pp. 3008–3017.

Strauss, A., and Corbin, J. M. 1997. *Grounded Theory in Practice*, Thousand Oaks, CA: Sage Publications.

Strong, D. M., Johnson, S. A., Tulu, B., Trudel, J., Volkoff, O., Pelletier, L. R., et al. 2014. "A Theory of Organization-EHR Affordance Actualization," *Journal of the Association for Information Systems* (15:2), pp. 53–85.

Svahn, F., Mathiassen, L., and Lindgren, R. 2017. "Embracing Digital Innovation in Incumbent Firms: How Volvo Cars Managed Competing Concerns," *MIS Quarterly* (41:1), pp. 239–254.

Tim, Y., Pan, S. L., Bahri, S., and Fauzi, A. 2017. "Digitally Enabled Affordances for Community-Driven Environmental Movement in Rural Malaysia," *Information Systems Journal*.

Tremblay, M. C., Hevner, A. R., and Berndt, D. J. 2010. "Focus Groups for Artifact Refinement and Evaluation in Design Research.," *Communications of the Association for Information Systems* (26:1), pp. 599–618.

Tuunanen, T., and Cassab, H. 2011. "Service Process Modularization Reuse Versus Variation in Service Extensions," *Journal of Service Research* (14:3), pp. 340–354.

Tuunanen, T., Hänninen, J., and Vartiainen, T. 2015. "Value Co-Creation for Cyber-Physical Systems in Mining and Construction Industry," in *Proceedings of the 21st Americas Conference on Information Systems (AMCIS)*, Puerto Rico.

Tuunanen, T. 2012. "Digital Innovation and Challenges for Service Research," *Journal of Information Technology Theory and Application (JITTA)* (13:2).

Ulaga, W., and Reinartz, W. J. 2011. "Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully," *Journal of Marketing* (75:6), pp. 5–23.

Vargo, S. L., and Akaka, M. A. 2012. "Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View," *Service Science* (4:3), pp. 207–217.

Vargo, S. L., and Lusch, R. F. 2004. "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing* (68:1), pp. 1–17.

Vargo, S. L., and Lusch, R. F. 2016. "Institutions and Axioms: An Extension and Update of Service-Dominant Logic," *Journal of the Academy of Marketing Science* (44:1), pp. 5–23.

Vargo, S. L., and Lusch, R. F. 2011. "It's all B2B…and Beyond: Toward a Systems Perspective of the Market," *Industrial Marketing Management* (40:2), pp. 181–187.

Vargo, S. L., and Lusch, R. F. 2017. "Service-dominant logic 2025," *International Journal of Research in Marketing* (34:1), pp. 46–67.

Vargo, S. L., and Lusch, R. F. 2008. "Service-Dominant Logic: Continuing the Evolution," *Journal of the Academy of Marketing Science* (36:1), pp. 1–10.

Vargo, S. L., Maglio, P. P., and Akaka, M. A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145–152.

Vargo, S. L., Wieland, H., and Akaka, M. A. 2015. "Innovation through institutionalization: A service ecosystems perspective," *Industrial Marketing Management* (44), pp. 63–72.

Volkoff, O., and Strong, D. M. 2013. "Critical Realism and Affordances: Theorizing It-Associated Organizational Change Processes," *MIS Quarterly* (37:3), pp. 819–834.

Walsham, G. 2006. "Doing Interpretive Research," *European Journal of Information Systems* (15:3), pp. 320–330.

Walsham, G. 1995. "Interpretive Case Studies in IS Research: Nature and Method," *European Journal of Information Systems* (4:2), pp. 74–81.

v. Wangenheim, F., Wünderlich, N. V., and Schumann, J. H. 2017. "Renew or Cancel? Drivers of Customer Renewal Decisions for IT-based Service Contracts," *Journal of Business Research* (79), pp. 181–188.

Webster, J., and Watson, R. T. 2002. "Analyzing the Past to Prepare for the Future: Writing a Literature Review," *MIS Quarterly* (26:2), pp. xiii–xxiii.

Wieland, H., Vargo, S. L., and Akaka, M. A. 2016. "Zooming Out and Zooming In: Service Ecosystems as Venues for Collaborative Innovation," in *Service Innovation*, M. Toivonen (ed.), Springer Japan, pp. 35–50.

Wünderlich, N. V., Kristina Heinonen, Amy L. Ostrom, Lia Patricio, Rui Sousa, Chris Voss, et al. 2015. "'Futurizing' smart service: implications for service researchers and managers," *Journal of Services Marketing* (29:6/7), pp. 442–447.

Xu, R., and Ilic, A. 2014. "Product as a Service: Enabling Physical Products as Service End-Points," in *Proceedings of the 35th International Conference on Information Systems (ICIS)*, Auckland, New Zealand.

Yin, R. K. 2008. *Case Study Research: Design and Methods*, Thousand Oaks, CA: Sage Publications.

Yoo, Y., Boland, R. J., Lyytinen, K., and Majchrzak, A. 2012. "Organizing for Innovation in the Digitized World," *Organization Science* (23:5), pp. 1398–1408.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research," *Information Systems Research* (21:4), pp. 724–735.

Yoo, Y. 2010. "Computing in Everyday Life: A Call for Research on Experiential Computing," *MIS Quarterly* (34:2), pp. 213–231.

Yoo, Y. 2013. "The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research?," *Journal of the Association for Information Systems* (14:5), pp. 227–236.

Zammuto, R. F., Griffith, T. L., Majchrzak, A., Dougherty, D. J., and Faraj, S. 2007. "Information Technology and the Changing Fabric of Organization," *Organization Science* (18:5), pp. 749–762.

Zittrain, J. 2006. *The Future of the Internet and How to Stop it*, New Haven, CT: Yale University Press.

E – **Article V**

Herterich, M.M., Uebernickel, F. and Brenner, W. (2016). “Stepwise Evolution of Capabilities for Harnessing Digital Data Streams in Data-Driven Industrial Services”. *MIS Quarterly Executive*. Vol. 15 No. 4.

Stepwise Evolution of Capabilities for Harnessing Digital Data Streams in Data-Driven Industrial Services [1 2]

Matthias M. Herterich
University of St.Gallen
9000 St.Gallen, Switzerland
matthias.herterich@unisg.ch

Falk Uebernickel
University of St.Gallen
9000 St.Gallen, Switzerland
falk.uebernickel@unisg.ch

Walter Brenner
University of St.Gallen
9000 St.Gallen, Switzerland
walter.brenner@unisg.ch

Abstract

Original equipment manufacturers (OEMs) face the challenge of building the capabilities to effectively harness the digital data streams flowing from their digitized industrial products to create innovative data-driven services. Based on insights from the digitization journeys of thyssenkrupp and SIEMENS, we provide a capability framework and actions that will guide OEMs as they progress through a stepwise evolution of six strategic service stages.

---

[1] Richard Watson is the accepting senior editor for this article.

[2] The authors thank thyssenkrupp AG and SIEMENS AG for their long-term support of this research project and for sharing their experiences of building digitally enabled service businesses. In particular, we thank Dr. Martin Hölz, CIO of thyssenkrupp, and Steffen Stang, Senior Director MindSphere Product Management and R&D at SIEMENS. We also acknowledge the contributions from organizations in the Competence Center "Industrial Services and Enterprise Systems (CC ISES)" at the Institute of Information Management at University of St.Gallen. This work is based on insights gained from Herterich, M. M., Eck, A. and Uebernickel, F. "Exploring How Digitized Products Enable Industrial Service Innovation – An Affordance Perspective," in *Proceedings of the 24th European Conference on Information Systems (ECIS)*, Istanbul, Turkey, 2016; Herterich, M. M., Uebernickel, F. and Brenner, W. "The Impact of Cyber-Physical Systems on Industrial Services in Manufacturing," *Procedia CIRP* (30), 2015, pp. 323-328; Herterich, M. M., Uebernickel, F. and Brenner, W. "Nutzenpotentiale cyber-physischer Systeme für industrielle Dienstleistungen 4.0," *HMD Praxis der Wirtschaftsinformatik*, 2015, pp. 665-680; Herterich, M. M., Uebernickel, F. and Brenner, W. "The Next Wave of Service Innovation — How cyber-physical systems can be leveraged for effective industrial equipment operations and empower industrial service," *Working Paper Series on Research in Information Systems Management and Business Innovation* (3), 2015.

Digital Data Streams Provide OEMs with Opportunities for Innovative Data-Driven Services

The "servitization" trend in manufacturing involves original equipment manufacturers (OEMs) shifting from selling products to offering integrated product-service systems.[3] With servitization, traditional physical products become commodities but increasingly act as distribution mechanisms for offering industrial services throughout their long lifecycles. Another trend is the recent emergence of digital data streams (DDSs), based on digital sensors and connectivity being embedded in hitherto purely physical products. DDSs are streams of real-time and dynamically changing information that have the potential to spur real-time action.[4]

Within the context of servitization, DDSs provide a variety of new opportunities for innovative data-driven service offerings and enable OEMs to innovate their service businesses in a stepwise manner. The resulting offerings allow OEMs to provide additional value to their customers and differentiate themselves from competitors. Despite these opportunities, however, manufacturing industry executives feel overwhelmed by the complexities of:

- Rapidly changing digital technology and its relevance to their individual, context-dependent digitization journeys
- Building the capabilities required in a structured, stepwise manner consistent with their organizational goals to iteratively realize short-term benefits
- Eventually establishing a digitized service platform and partnering with other organizations in the service ecosystem to harness the enormous opportunities that the generative[5] potential of digitized industrial products can offer.

---

[3] Servitization is a growing trend in the manufacturing industry resulting from the commoditization of physical industrial goods and shrinking margins in the product business. See Lightfoot, H., Baines, T. and Smart, P. "The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends," *International Journal of Operations & Production Management* (33:11/12), 2013, pp. 1408-1434; Neely, A "Exploring the Financial Consequences of the Servitization of Manufacturing," *Operations Management Research* (1:2), 2008, pp. 103-118; and Ulaga, W. and Reinartz, W. J. "Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully," *Journal of Marketing* (75:6), 2011, pp. 5-23.

[4] Piccoli, G., and Pigni, F. 2013. "Harvesting External Data: The Potential of Digital Data Streams," *MIS Quarterly Executive* (12:1), pp. 53-64.

[5] Generative capacity describes a technology's overall ability to produce unprompted change driven by large, varied and uncoordinated audiences. For more information, see Zittrain, J. L. "The Generative Internet," *Harvard Law Review* (119:7), 2006, pp. 1974-2040.

This article identifies the actions manufacturing executives can take to build up and harness capabilities with respect to DDS and technology, internal and managerial capabilities and external collaboration and value co-creation to co-create value in the field of data-driven industrial services. The guidance in this article is based on a capability framework and six strategic data-driven industrial service stages that address different organizational goals. The service stages typify the digital transformation journey of firms in the manufacturing industry.

First, we briefly describe the two organizations we studied, thyssenkrupp and SIEMENS. (The Appendix describes the research method used for this article.) We then introduce the dimensions of the capability framework and provide details of the six strategic data-driven industrial service stages. We illustrate each stage through case examples from thyssenkrupp and SIEMENS. Finally, we provide guiding principles and actions for CIOs and other manufacturing industry executives. These principles and actions will help them to better understand the mechanisms for leveraging DSSs in the industrial services business.

A Brief Introduction to thyssenkrupp and SIEMENS

thyssenkrupp

thyssenkrupp is a diversified industrial group with traditional strengths in materials and a growing share of capital goods and services businesses. Its business is structured by six business areas: Components Technology (CT), Elevator (ET), Industrial Solutions (IS), Material Services (MX), Steel Europe (SE) as well as Steel Americas (AM). Around 155,000 employees in nearly 80 countries work with passion and technological expertise to develop high-quality products and intelligent industrial processes and services for sustainable progress. In fiscal year 2014/2015, thyssenkrupp generated sales of around €43 billion.

thyssenkrupp's elevator business is an early adopter of augmenting industrial products with digital technology aimed at harnessing DDSs for its services business. The current focus is on maintenance, repair and overhaul (MRO) activities for servicing its products throughout their lifecycle. In October 2015, the Elevator Technology business area rolled out "MAX," a solution for digitizing the industrial services business to efficiently and effectively service its product portfolio of passenger and freight elevators, escalators, moving walks, passenger boarding bridges and stair and platform lifts.[6]

[6] For more information, see: https://max.thyssenkrupp-elevator.com.

We also provide illustrative examples from thyssenkrupp's Material Services business area, which is leveraging DDSs to optimize the operation and capacity usage of machinery for steel processing on the factory floor.

SIEMENS

SIEMENS is the largest engineering company in Europe and provides a wide range of electrical engineering and electronics-related products and services. With more than 360,000 employees, the company operates in around 190 countries and is structured into 10 business divisions. As well as selling products, industrial services play an increasingly large role in SIEMENS' business. It provides a variety of product-complementing service offerings and has established dedicated organizational functions to centralize and harmonize these offerings. The functions include support and consulting services, training services, field and maintenance services, and plant data services. In 2015, SIEMENS generated service sales of 16 billion euros ($17.9 billion), with an expected annual growth of 15%.

SIEMENS has developed "MindSphere," an open digital platform to leverage DDSs originating from digitized products. MindSphere provides a backbone for additional innovative, data-driven industrial service offerings.

Drawing on insights from both thyssenkrupp and SIEMENS, we have built a comprehensive view of how DDSs from digitized products impact the industrial services business. While thyssenkrupp focuses mainly on improving existing service offerings through digitizing products, SIEMENS seeks new revenue streams from radical service innovation.

An OEM's Digitization Journey Has Six Strategic Data-Driven Industrial Service Stages

OEMs need to establish a set of capabilities to offer a particular type of service.[7] These capabilities fall into three areas—digital data streams and technology, internal and managerial, and external collaboration and value co-creation. Using these capability areas as a starting point, we ran focus group workshops with executives from thyssenkrupp and SIEMENS during which we categorized their data-driven industrial services into

[7] The data-driven services proposed in this article address the specific characteristics of the service business in industrial manufacturing. For an overview of DDS archetypes, see Piccoli, G. and Pigni, F. op. cit., 2013.

each area. Then, by also taking organizational goals into account, we identified six strategic data-driven industrial service stages—engineering and R&D services, reactive MRO activities, complementary digital services, proactive MRO activities, field service empowerment, and outcome- and performance-based offerings. Together, these stages represent the typical stepwise digital transformation journey of OEMs in the manufacturing industry. Further workshops with executives from the other manufacturing companies validated these six stages. Figure 1 provides an overview of the six-stage stepwise evolution of data-driven industrial services for OEMs in the manufacturing industry. We saw this evolution in both thyssenkrupp and SIEMENS.

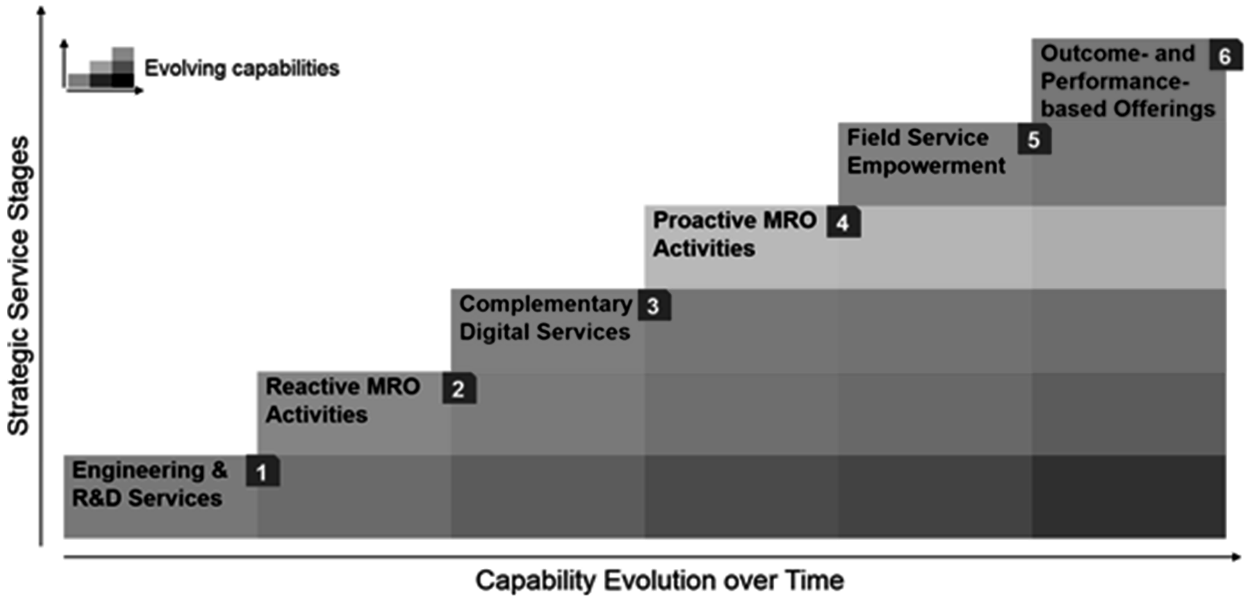


Figure 1. Six Stages of Capability-based and Goal-oriented Strategic Industrial Services

As the capabilities evolve through the six stages, with those required for implementing the different service types building on each another, OEMs can harness the potential of DDSs for industrial services. Individual services address different organizational goals, and executives have to make decisions on which services they want to focus on and how they want to evolve their industrial services business in line with these goals and the competitive situation of their firm. Based on these decisions, they need to systematically build up the required capabilities. Capabilities that are necessary to implement foundational services can be further developed to enable more sophisticated services at later stages of the journey. The six-stage journey is, in effect, a generalized goal-oriented implementation roadmap, with the endpoint being harnessing the potential of DDSs in outcome-based offerings.

The capability framework depicted in Table 1 provides an overview on the capabilities needed at each stage of the stepwise journey. The dimensions of the framework are the three capability areas identified above—digital data streams and technology, internal and management capabilities, and external collaboration and value co-creation. OEM executives should consider this framework, together with their competitive situation and organizational goals, when making decisions about data-driven industrial services.

Capability / *Service Stage*	1 Eng. and R&D Services	2 Reactive MRO	3 Compl. Digital Services	4 Proactive MRO	5 F. Service Empowerment.	6 Outcome-based Offerings
Digital Data Streams and Technology						
D1: Data collection (mode of data collection and timeliness)						
D1.1: Batch-based collection of historic operational product data	X	-	-	X	-	-
D1.2: Continuous streaming of current operational product data	-	X	X	-	X	X
D2: Data analysis						
D2.1: Simple rule-based data analysis	X	X	-	-	X	-
D2.2: Advanced analytical models	-	-	-	-	-	X
D2.3: Machine learning algorithms	-	-	X	X	-	-
Internal and Managerial Capabilities						
D3: Service operations						
D3.1: Human-centered service operations	X	X	-	-	-	-
D3.2: Semi-automated service operations	-	-	-	X	X	-
D3.3: Automated service operations	-	-	X	-	-	X
D4: Interdisciplinary and cross-functional collaboration						
D4.1: Traditional organizational functions with temporary projects	X	-	-	-	-	-
D4.2: Service-oriented organizational structure	-	X	X	X	X	-
D4.3: In-depth interdisciplinary internal and external collaboration	-	-	-	-	-	X
D5: Organizational culture						
D5.1: Focus on physical products and value-in-exchange	X	X	-	-	-	-
D5.2: Focus on services and value-in-use	-	-	X	X	X	X
External Collaboration and Value Co-Creation						
D6: Customer involvement and market orientation						
D6.1: No customer/partner involvement	X	X	-	-	X	-
D6.2: Integration of customer needs	-	-	-	X	-	-
D6.3: In-depth customer/partner integration	-	-	X	-	-	X
D7: Inter-organizational information sharing						
D7.1: Isolated, standalone, no information sharing	X	-	-	-	-	-
D7.2: Limited, manual information sharing	-	X	-	X	-	-
D7.3: Standardized information sharing via APIs and platform	-	-	X	-	X	X

Table 1. Key Capabilities for Harnessing Digital Data Streams at each Strategic Services Stage

The capabilities on the digital data streams and technology dimension focus on the properties of DDSs and digitized industrial products. Internal and managerial capabilities focus on organizational and internal capabilities. Capabilities on the external collaboration and value co-creation dimension focus on the service ecosystem and inter-organizational collaboration. This framework provides executives with a managerial tool that highlights relevant capabilities and their dedicated characteristics. Depending on the organization's goals and competitive situation, the framework helps executives to identify which capabilities need to be further developed to offer a particular service and thus leverage DDSs for their industrial services business effectively.

Service Stage	Description	Business Benefits
1 Engineering and R&D Services	Operational data of products in the field are leveraged to engineer future product generations.	Shortened product innovation cycles and triggers for incremental product innovation.
2 Reactive MRO Activities	Failures in product operations can be anticipated by continuously monitoring product operations in the field. Based on anomalies, MRO activities can be triggered.	Higher service quality, reduced product downtimes and higher customer satisfaction.
3 Complementary Digital Services	Operational product data is harnessed in digital services that address specific customer needs during the long operations lifecycle of industrial products.	Decreased operating costs and better product performance.
4 Proactive MRO Activities	Potential failures in product operations can be anticipated by continuously monitoring product operations in the field and comparing current data with historic data. Based on historic trends, MRO activities can be triggered before an actual breakdown occurs.	Higher service quality, reduced product downtimes and higher customer satisfaction.
5 Field Service Empowerment	Insights derived from DDSs can be provided to field service technicians and remote experts in service centers to optimize existing service processes.	Higher service efficiency, reduction in service resources and increased service quality.
6 Outcome-based Offerings	Instead of selling products and servicing them based on advanced maintenance strategies, OEMs become responsible for the entire product operation. Product operators pay based on actual product usage.	Stronger customer loyalty, continuous revenue streams and stronger lock-in effects.

Table 2. Overview of Data-driven Industrial Services and Business Benefits

Table 2 briefly describes the business benefits of each of the six strategic service stages as they relate to organizational goals. As such, it provides an overview of the services that can be harnessed as the capabilities in each of the three framework dimensions evolve over time.

Service Stage 1: Engineering and R&D Services

Stage Description. Stage 1 services are the most foundational type of service based on DSSs originating from digitized industrial products. They leverage historic operational product data (D1.1 in Table 1) to engineer future product generations. Based on simple (rule-based) data analysis (D2.1), insights into product failure behavior, failure causes and spare parts required can be used to assess the total costs of product operations and engineer better products. Using historic operational data in this way incrementally enhances products in terms of quality and/or sustainability. Causes of failures during the product lifecycle can be identified and eradicated; unused product features can be eliminated to save manufacturing costs. Total product lifecycle costs become transparent and controllable.

Case 1 illustrates how thyssenkrupp leveraged foundational digital technology that was implemented in a "lighthouse"[8] project to generate awareness of the potential of DDSs for its operations.

Case 1. Leveraging Operational Product Data to Optimize Shop Floor Operations at thyssenkrupp

In 2012, thyssenkrupp's Material Services business area kicked off an early "lighthouse" project to collect operational product data in dedicated steel processing facilities. Selected shop floor machinery in one steel service center was equipped with data loggers. Operational data on machine downtimes, machine operations and set-up times was collected. Management's goals were to replace paper-based tracking of machine operations, to identify reasons for production downtimes, and to optimize production scheduling, and shop floor planning and design. Besides extending this approach and leveraging the solution in operations of various other production sites, this early initiative provided valuable first learnings for the journey toward effectively leveraging DDSs. The project enabled thyssenkrupp Material Services to gain first experiences machine-to-machine communication for future projects. Data collected allowed early analytical models to be evaluated and tested, and to corroborate sensor set-up and data quality, which impacted the meaningful interpretation of operational data. The learnings from this early lighthouse project were extended to the Business Unit thyssenkrupp Materials Services. They helped generate awareness of harnessing DDSs flowing from industrial products for thyssenkrupp 's product and service business. Finally, this Stage 1 initiative allowed the organization to experiment with operational product data, resulting in a deeper understanding of how future DDS implementations could generate benefits.

> *"In that early stage, our No. 1 motivation was to get a feeling for the power of operational product data for our business. We obtained high-resolution data for the first time. The first thing we did was to identify capacity bottlenecks and optimize our shop floor layout in one of our key production facilities.*"
> Thomas Materna, Head of Technics Department, thyssenkrupp Material Services

[8] As well as its original purpose, a lighthouse project aims to have a signal effect for numerous follow-up projects as they look towards it for inspiration and guidance.

Stage 1 Characteristics. As Case 1 shows, the first steps toward harnessing DDSs for industrial service innovation are difficult, because short-term benefits from early explorative efforts are often not evident. In both thyssenkrupp and SIEMENS, the data-driven engineering and R&D service emerged as an early quick-win opportunity in the digital transformation journey. Data was analyzed manually (D3.1) by product engineers in temporary project-based organizational structures (D4.1) and a product-oriented organizational culture (D5.1). For Stage 1 “lighthouse” projects such as these, no involvement of customer or partner organizations is necessary (D6.1). There is no need to set up capabilities for sharing information between organizational entities (D7.1).

In summary, requirements in this first experimental stage of the digitization journey are rather basic. Foundational capabilities are developed to generate initial benefits that contribute to the OEM’s goal of engineering better products. Both organizations implemented capabilities and learned lessons from these early attempts that were the foundation for exploiting continuous data streams in a more mature way. For instance, thyssenkrupp has to manage a large variety of products in the field, due to the long lifecycles (often several decades) of industrial products. In addition, the installed base is constantly evolving, resulting in altered standards and technical requirements.

Hence, the most fundamental challenge at Stage 1 is to establish a common denominator for connecting the industrial products in a way that allows standardized and consistent data across the entire product portfolio. SIEMENS was able to draw on the standardized interfaces in its programmable logic controllers:

“In the early days, we developed a generic data collector that allows [us] to capture data over a limited period of time. Today, we are able to continuously feed digital data streams of various kinds of equipment into 'MindSphere,' our open data platform.” Christian Heck, Head of Service Line Process Data Analytics, SIEMENS AG

To master this challenge, SIEMENS management set up a temporary interdisciplinary organizational unit to combine the necessary internal expertise for a data-driven industrial services business from the outset. (This unit was similar to the corporate technology department at thyssenkrupp.) During the early stages, leveraging DDSs from digitized industrial products is rather experimental. Manual effort by highly skilled engineers with contextual knowledge about product operations is needed to derive early useful and significant insights.

Service Stage 2: Reactive Maintenance, Repair and Overhaul Activities

Stage Description. Failures in product operations can be anticipated by continuously streaming current operational product data (D1.2) to monitor product conditions and wear and tear of product components. Anomalies in the operation of individual components can be identified by using simple variance analysis of incoming data streams or interpreting error codes of the product (D2.1). Triggering MRO activities based on these analyses results in incremental enhancement of the traditional human-centered MRO service operations (D3.1).

thyssenkrupp's elevator business has historically focused on MRO service activities because of the dedicated market characteristics and high margins. Increasing operational efficiency without changing the business model therefore has an immediate positive effect on service earnings. Because of these competitive characteristics, the Elevator Technology business area has built an effective service-oriented organizational structure (D4.2). However, the product business can still be regarded as the primary focus resulting in a largely unchanged product-centric organizational culture (D5.1). In contrast, SIEMENS has a limited traditional MRO business and pursues a different strategy by directly focusing on radical service innovation based on scalable complementary digital services (Service Stage 3).

Using thyssenkrupp's Elevator Technology business area as an example, Case 2 provides in-depth insights from an early attempt to implement reactive MRO activities based on using DDSs to implement an incremental service innovation.

Case 2. Early Attempts to Leverage Condition Monitoring in thyssenkrupp's Elevator Business

Acting fast when an industrial product breaks down is critical. Very early on and before the trend of analyzing operational product data came up, thyssenkrupp's Elevator Technology business area started to define error codes for dedicated failure patterns of its products through the VISTA project in its U.S. MRO organization. With the implementation of VISTA, the condition of elevators was continuously monitored based on easy-to-measure critical operating indicators such as door functionality or leveling zones of the car in the elevator shaft. When the indicators crossed threshold values, predefined error codes were sent to a central platform.

VISTA failed, however, for two main reasons. First, the service organization could not rely on the information originating from the system because the data retrieved from VISTA was not always correct. Technicians arriving to repair elevators, which they thought had specific problems, often encountered unexpected situations because only limited contextual information was provided by VISTA. The poor data quality resulted in limited acceptance of the system among service technicians. Second, data obtained from VISTA was incomplete; the system only provided limited data on a predefined set of error codes. No detailed information was transmitted on how and why the failure happened.

The sparse raw data collected via VISTA meant that follow-up initiatives and plans to leverage predictive models and advanced machine learning algorithms on rich historic operational data could not be implemented. This resulted in limited commitment to integrating VISTA into existing processes and limited awareness of the system among service technicians. Initially, transmitted error codes were only filed with the service history of the dedicated product. To avoid misallocation of resources, error codes were not used to trigger any MRO activities such as sending alerts to the people responsible or automatically dispatching technicians for timely troubleshooting. Furthermore, service personnel were not trained to use the data from the system in their day-to-day operations. As a consequence, limited awareness of the system among service staff resulted in restricted usage.

Stage 2 Characteristics. In contrast to SIEMENS, thyssenkrupp defines threshold values for its reactive MRO activities and transmits error codes when the threshold values are crossed, which triggers MRO activities. The products report errors themselves; there is no manual involvement by the customer. Although the elevator DDSs trigger reactive MRO activities, the MRO activities are still performed by field service technicians (D7.2). Thus, reactive MRO activities based on DDSs can be triggered in an immature MRO business without any standardized and harmonized processes. Implementing the necessary capabilities for Stage 2 services is a significant step toward proactive MRO activities (Stage 4) and outcome-based offerings (Stage 6).

Service Stage 3: Complementary Digital Services

Stage Description. Operational product data is leveraged in complementary digital services that address customer needs throughout the long operations lifecycle of industrial products. At this stage, OEMs can offer an entirely new class of product-complementing digital services. As physical industrial products become increasingly commoditized, digital services allow OEMs to differentiate themselves from competitors. Insights based on DDSs are harnessed to (1) offer services that optimize and complement product operations or (2) support customer operations. For instance, a forklift manufacturer could manage and optimize its customers' fleet, or a manufacturer of elevators and escalators could provide a service to manage flows of people in large buildings such as airports. OEMs can even become data providers through selling raw data as a digital service to other stakeholders via standardized interfaces or digital platforms. Stakeholders can then leverage this data for their own value-creation purposes.

Stage 3 data-driven industrial services can result in decreased product operating costs, better product performance, improved energy efficiency, greater product usage, enhanced safety or other benefits for the customer. Early on, SIEMENS recognized the customer need for digital services, as well as their commercial potential, and established a portfolio of selected services. In contrast, thyssenkrupp's primary goal was to incrementally improve its MRO activities (see Stages 2 and 4) instead of embarking on radical service innovation through a dedicated digital services business. Despite this primary goal, in 2012, thyssenkrupp decided to invest in its technology foundation by launching "unite," a group-wide initiative to consolidate and standardize its IT landscape. Unite enables thyssenkrupp to introduce complementary digital services.

Case 3 illustrates how SIEMENS has established a digital platform that forms the foundation for offering digital services in a professional and scalable way.

Case 3. SIEMENS' MindSphere, an Open Digital Platform for Digital Industrial Service Offerings

In 2013, SIEMENS started to offer product-complementing digital services with the aim of optimizing the operations of large production facilities and industrial plants. Based on the servitization trend in the manufacturing industry, SIEMENS wanted to establish a new kind of industrial services business that goes beyond operational, hotline-based problem solving for product operations. The starting point was workshops and need-finding sessions with representatives from loyal customer organizations. SIEMENS then began to establish various service lines and digital services that addressed the most relevant customer needs. For instance, one service focused on the data-driven optimization of energy efficiency at large production facilities. Another plant data service was aimed at the operational optimization of large plants. To implement these services and collect the necessary data, products and control technology were temporarily augmented with data loggers and sensor technology. After collecting operational data for a couple of weeks, engineers employed linear optimization and data analytics to derive actionable insights to configure machinery.

Although data consulting services such as these make use of standardized DDSs, they involve a great deal of manual effort to understand (1) the individual needs and objectives of the customer organization and (2) the operational processes and machinery needed to derive meaningful and actionable optimization potential. Qualified experts were needed to implement the changes in projects at the customer site and follow-up consulting projects were set up to achieve this.

> *"After running the service lines for a couple of months, we quickly noticed that all our analytical services have one thing in common. The data has to be captured and analyzed, and finally insights have to be provided to various stakeholders. And then it became obvious that we should develop a shared platform that is able to do those things in a standardized way. This idea is the beginning of our journey to generating additional value from standardized service offerings that are provisioned by leveraging a digital platform."* Frank Konopka, Head of Service Line Plant Cloud Services, SIEMENS AG

In March 2015, SIEMENS launched "MindSphere", a digital platform that allows DDSs generated by digitized industrial products to be harnessed in a standardized and highly flexible way. Based on an open architecture, MindSphere connects industrial products and production facilities and serves as a foundation for offering modular, standardized digital services throughout the operations lifecycle of industrial products. MindSphere's standardized modules allow SIEMENS to offer a highly flexible digital service portfolio for optimizing product operations in terms of performance, energy and resource consumption, usage, and more. With the MindSphere platform, SIEMENS has established the basis for providing complementary digital services and positioned itself as a platform service provider in the manufacturing industry.[9]

Stage 3 Characteristics. Although providing digital services can be considered a radical innovation, the technology requirements are not overly complex and very much depend on the actual service offering. OEMs should therefore consider implementing flexible and modular digital service platforms to enable a wide variety of digital services. A platform approach provides core functionality, such as the collection, transmission and safe storage of data. It also provides the foundation of a development environment for rapidly creating applications and algorithms to address individual customer needs with little additional effort. For instance, SIEMENS' MindSphere platform provides a variety of foundational capabilities in terms of data collection, storage and data analysis. It is a comprehensive data-hosting platform that comprises device management and the ability for continuous data collection (D1.2), product connectivity, scalable data processing and analysis based on machine learning algorithms (D2.3).

Usually, data analysis is 80% data cleansing and 20% actual data analysis. This means that fancy algorithms and statistical analysis is done in the last 20%. The first 80% is hard work. And to have the slightest chance to derive robust and wise results, this hard work usually has to be done by highly skilled people who have to understand the product's application in the field as well as the specifics of the shop floor environment at the customer site. Achim Knebel, Vice President MindSphere Operations, SIEMENS AG

From an organizational perspective, OEMs have to overcome three key challenges to offer Stage 3 digital services. First, they must rethink their service operations. Although the necessary algorithms must be implemented before services can be offered, only a limited workforce is needed to provide a service, since digital services are offered on the basis of automated service operations (D3.3) to ensure scalability. This results in a shift of the skill mix within an organization toward more highly qualified personnel, such as the data scientists or domain experts needed to build and design digital services. Second, OEMs must develop capabilities to understand the needs of potential customers (D6.3). They must identify the potential benefits for customers and other beneficiaries in the service ecosystem that can be addressed by digital services. SIEMENS conducted co-innovation workshops and experimental proof-of-concept projects with customers.

[9] For more information on MindSphere see http://www.industry.siemens.com/services/global/en/portfolio/plant-data-services/cloud-for-industry/Pages/Default.aspx.

Third, OEMs need to establish a service-oriented organizational structure that is geared toward the market and thematically clustered along the lines of potential service offerings (D4.2).

As described in Case 3 above, SIEMENS established “service lines” to bundle expertise for dedicated service offerings. Service lines are responsible for individual service offerings. They focus on the actual value-in-use offerings for customers instead of value-in-exchange offerings and industrial products based on a traditional goods-dominant logic (D5.2).

To provide Stage 3 services, the role of the internal IT department also needs to change. Instead of just providing infrastructure for internal operations, it needs to have a market-facing role when the organization offers digital services via standardized technical interfaces and digital platforms (D7.3). The IT department becomes responsible for services that are consumed by external customers. Moreover, OEM executives must decide to what degree they want to build up internal capabilities and work together with external partners to offer digital services. SIEMENS aims at radical service innovation by investing in its digital services business, while thyssenkrupp focuses on maximizing profits generated by a strong MRO business.

Service Stage 4: Proactive Maintenance, Repair and Overhaul Activities

Stage Description. Potential product failures can be anticipated by continuously monitoring product operations in the field and comparing current operational data with historic data. Based on advanced data analytics, MRO activities can be triggered before an actual breakdown happens. By proactively taking countermeasures before a breakdown occurs, downtimes can be reduced to a minimum. With a traditional reactive MRO process, a breakdown results in costly downtime despite customer organizations demanding high uptimes. Once a breakdown has occurred, field service visits have to be scheduled to solve the problem.

However, research on engineering and maintenance strategies has found that many industrial product failures can be predicted long before they occur.[10] By continuously comparing DDSs flowing from condition-monitoring technology with historic product data and using algorithms that focus on early detection of anomalies, it is possible to

[10] For an overview on proactive maintenance strategies, see Bloch, H. P. and Geitner, F. K. *Machinery Failure Analysis and Troubleshooting*, 2nd edition, Gulf Publishing Co., 1983.

generate forecasts about potential breakdowns. With such a data-driven and proactive maintenance strategy, potential anomalies can be identified before breakdowns happen. The result is a decrease in mean time to repair (MTTR), increased mean time between failures (MTBF), a better ratio between planned and unplanned MRO activities, and predictability of field service incidents. The existing MRO business thus becomes more predictable and can be scheduled more effectively. OEMs and their service organizations come one step closer to realizing the vision of zero unplanned downtime.

Because of the traditionally strong MRO business in its elevator and escalator division, thyssenkrupp decided to further strengthen its competitive position by creating the foundation for proactive MRO activities. In the case of SIEMENS, however, the MRO business plays a minor role. Hence, thus far SIEMENS has only put limited efforts into comprehensively digitizing its MRO business.

Case 4 illustrates how the elevator division of thyssenkrupp sets the foundation for a proactive MRO business by evolving the capabilities of its reactive Service Stage 2 MRO business.

Case 4. thyssenkrupp's MAX as a Foundation for Proactive MRO Activities

In the elevator business, field service plays a key role in ensuring uninterrupted product operation. thyssenkrupp's Elevator Technology business area employs more than 20,000 skilled technicians globally to keep its elevators running. Its field service business is divided into regional divisions, with country-specific subsidiaries. Because of the high MRO costs, thyssenkrupp continuously seeks ways to make the elevator service business more efficient and improve service quality. For instance, in the early 2000s, the U.S. service division experimented with condition-monitoring technology in a project called VISTA (see Case 2 above). There then followed a multi-year effort to understand the specific needs of various MRO business stakeholders, and various prototypes and pilot projects were implemented. These activities, together with the lessons learned from VISTA, resulted in the Elevator Technology business area deciding in 2013 to collaborate with Microsoft on harnessing the DDSs from millions of elevators in the field. The aim was to set the stage for a "smart" MRO service business. By bringing together data scientists with elevator domain experts, a highly interdisciplinary team launched MAX in October 2015 as a solution to support the elevator division's global service organizations.

MAX is based on digitized elevator control units, which continuously transmit data about the condition of individual elevators to a central digital platform, based on Microsoft's Azure Cloud. Machine learning algorithms are used to analyze incoming data and continuously calculate the remaining life time of individual components for each elevator. thyssenkrupp's process standardization and harmonization initiative, known as "data and process harmonization" (daproh), allow easy future integration of MAX as a technology foundation for proactive MRO activities in local MRO service organizations. Thus, MAX serves as a single solution for data-driven proactive MRO activities across the globe. Based on smart algorithms, it schedules service tasks ahead of elevator breakdowns, detects when individual components have to be exchanged early, and empowers service staff with in-depth insights into elevator operations (see screenshot below).

"We wanted to go beyond the industry standard of preventative maintenance, to offer predictive and even pre-emptive maintenance. […] MAX is a key business growth strategy for thyssenkrupp Elevator. […] The phased launch approach allows us to introduce the solution in priority markets first and build its strength incrementally, to enable organic developments to be made in line with the constantly evolving market conditions." Andreas Schierenbeck Chief Executive Officer, thyssenkrupp Elevator[11]

Instead of just reacting to alarms, thyssenkrupp can use insights derived from DDSs to identify the countermeasures required before breakdowns occur. Furthermore, service staff can remotely put an elevator into diagnostics mode, or send it to another floor depending on local regulations and law. In summary, product downtimes and the travel times of service technicians have significantly decreased, resulting in improvements in customer satisfaction and service efficiency, and reductions in costs.

Stage 4 Characteristics. Based on the timely batch-based collection of operational product data (D1.1) from the installed product base, machine learning algorithms (D2.3) can identify trends in the wear and tear of individual product components. As more historic data is made available, more accurate predictions of future breakdowns can be made. As well as having the necessary advanced technical capabilities in place, the organizational structure of the MRO business needs to be adapted. With semi-automated service operations (D3.2), administrative back-office support staff can be reduced because tasks can automatically be scheduled once experienced service technicians have reviewed the automated MRO task suggestions. The MRO business needs to have a service-oriented organizational structure (D4.2). All its activities and the organizational

[11] Source: https://max.thyssenkrupp-elevator.com/assets/pdf/TK-Elevator-MAX-Report.pdf

culture should focus on customer-facing offerings and on the value-in-use of products and services (D5.2) that address customer needs (D6.2).

In Stage 4, OEMs therefore need to build up capabilities that allow information sharing with external service organizations (D7.2). For instance, platform capabilities that were built to offer complementary digital services (Service Stage 3) can be used to sell predictive MRO information to external MRO organizations.

Service Stage 5: Field Service Empowerment

Stage Description. Insights based on DDSs can be provided to field service technicians and remote experts in service centers to optimize existing service processes. Field service staff can be incrementally empowered in three distinct ways.

First, DDSs can support and empower both field service staff and remote experts in carrying out their day-to-day tasks. Service technicians can compare current operational product data (D1.2) with historical data to obtain a deep understanding of the state of a machine. This results in faster resolution of on-site problems and higher product uptimes. Remote experts can also be supported with in-depth data on the actual condition of the product and its components. If anomalies are identified from rule-based data analysis (D2.1), an in-depth initial diagnosis can be performed by experts (D3.1) who remotely connect to the product.

Second, field service staff can be empowered by optimizing the support processes of MRO activities. For instance, spare parts management can become more efficient. Based on the (potential) defects identified, relevant spare parts can be ordered in advance.

Third, technical capabilities that allow remote control of products can be leveraged to digitize and automate service activities that were previously carried out by field service technicians. With the increasing use of software to control industrial machines, software defects are more likely to be the reason for product failure.[12] Non-hardware-based defects can be fixed remotely leveraging actuators and a bi-directional communication infrastructure. With remote capabilities, experienced service agents can be used more effectively by locating them in the back office service center (D4.2).

SIEMENS focuses more on implementing digital services (Service Stage 3) and outcome-based offerings (Service Stage 6), whereas thyssenkrupp has taken the first steps

[12] Source: https://max.thyssenkrupp-elevator.com/assets/pdf/TK-Elevator-MAX-Report.pdf

toward increasing the value-in-use of its products (D5.2) by empowering field service technicians through insights generated from DDSs.

Case 5 describes how thyssenkrupp leverages capabilities that were originally deployed to conduct proactive MRO activities (Service Stage 4) but now also empower its field service technicians beyond just triggering MRO activities proactively.

Case 5. How thyssenkrupp Uses MAX for Field Service Empowerment and the Optimization of Service Characteristics

Elevators are industrial products with long lifecycles. Given this, MRO activities play a crucial role in keeping the products in working order. Thus, efficient MRO activities are of great importance for OEMs like the Elevator Technology business area of thyssenkrupp. Its regional service organizations have historically used different tools to support their field service technicians. Combining DDSs and the remote control capabilities of MAX allows thyssenkrupp to support field service staff and digitize or even automate MRO activities. However, harnessing DDSs from digitized industrial products to increase efficiency by automating service processes requires a standardized and harmonized MRO business. In early 2011, thyssenkrupp's board recognized the need for standardization across the regional field service organizations and launched the "daproh" process standardization and harmonization change program, with the aim of centralizing and harmonizing master data and processes. Service processes were identified as a key element of the program. The major objectives of daproh were harmonized, best-in-class business processes characterized by high efficiency, cost-reductions and reusability.

After an in-depth assessment of the status quo in individual service regions, standardized process blueprints were defined with the assistance of executives from regional service organizations. Standardization encompassed both tools and information systems. In the past, elevator field service technicians used rugged devices to connect to an elevator during their on-site visits. These mobile diagnosis tools were used to read out the error memory of the elevator. The error codes provided the technicians with information on causes of failures. Because of different product models and product generations, a variety of devices was needed.

In the information systems area, the MAX system makes rich data on the current condition of individual elevators available to service personnel. Service technicians benefit from MAX in three main ways. First, they can, on the basis of various error codes, remotely discover the situation of an elevator without the need for an on-site visit. thyssenkrupp therefore has powerful mobile work support systems that integrate the insights provided by MAX. Second, MAX allows remote connection to a defective elevator in some areas depending on local regulations and law. This capability means that non-hardware-based problems can be solved by an expert in a remote service center.

> *"MAX also marks a game-changing moment in the relationship between elevator providers and building managers, transforming sometimes negative, reactive service into a more positive, proactive approach. With MAX, thyssenkrupp's global team of over 20,000 field service engineers have a fact-based "wingman" to alert them in advance to pre-issue repairs." Sergio Cardoso, Executive Vice President Field,thyssenkrupp Elevator*[13]

[13] Source: https://max.thyssenkrupp-elevator.com/assets/pdf/TK-Elevator-MAX-Report.pdf

Third, MAX helps with spare parts management. In traditional service processes, the spare parts required to fix a breakdown could not be identified before seeing the defective product. Thus, two or more journeys to the same elevator were necessary when fixing breakdowns that required additional spare parts. MAX supports service staff by flagging individual components that need to be replaced before they face a major error or breakdown. As a consequence, the "first time fix rate" has been increased significantly.

In summary, MAX significantly improves service efficiency and service quality, resulting in increased elevator uptime and customer satisfaction. As a next step, management is considering implementing interfaces to CRM and workforce scheduling systems to leverage customer data and information on workforce availability so that dispatch to service incidents can be based on service contracts and skill sets.

Stage 5 Characteristics. At this stage, the requirements for data collection (D1) and data analysis (D2) are not onerous. However, powerful mobile workforce support systems need to be in place to distribute insights on product operations to service technicians (D7.3) and empower human-centered service operations in the field (D3.1). From an organizational perspective, external efforts in Stage 5 are also limited, as customer and partner organizations are not involved in internal MRO processes (D6.1).

However, OEMs need to set up new and important organizational functions in their back-office service centers. The role of these functions is to conduct pre-analysis of potential problems and provide field staff with support based on insights derived from DDSs (D4.2). This arrangement means the experience of senior field staff can be leveraged in central service centers instead of sending them on long journeys to customers' premises.

Once field service processes have been standardized across regional service subsidiaries, the full potential of providing advanced data-driven services can be realized, rather than merely triggering MRO activities. These services will be based on DDSs (Service Stages 2 and 4) but will also empower field service staff by drawing on centralized service centers and mobile work support systems. Highly efficient MRO activities provide the foundation for completely internalizing the costs of MRO activities in outcome-based offerings (Service Stage 6). Thus, thyssenkrupp devotes much effort to optimizing field service activities to lay the foundation for outcome-based offerings.

Service Stage 6: Outcome-Based Offerings

Stage Description. Outcome-based offerings fundamentally change the way in which value is delivered to customers. In earlier stages, the value propositions of OEMs are based on selling products and services as one-time transactions (i.e., value-in-exchange). In contrast, outcome-based services assure product uptimes and the value propositions are the business outcomes of industrial products, plants and machinery. Outcome-based offerings thus support customer organizations directly in co-creating value. Instead of selling products and servicing them based on advanced maintenance strategies, OEMs become responsible for the entire operation of the product and are paid according to product usage and the actual value it generates for the customer organization (i.e., value-in-use) (D5.2).[14] Thus, the overall benefits to the customer organization generated by the OEM are quantified and transparent, allowing the OEM's revenue to be linked directly to the actual performance of the customer organization. For instance, the fleet sizes of industrial products such as forklifts can be dynamically scaled up or down to help customers optimize product usage.

Adjusting product models in accordance with actual usage results in closer relationships with customers throughout the long product lifecycles, and thus assures steady revenue streams and more intimate ties that competitors will find hard to break. Stage 6 combines many of the individual building blocks of Stages 1 to 5, and for many OEMs is the final destination of the digitization journey within the context of the industrial services business. As Case 6 shows, SIEMENS has reached this final stage.

Case 6. Outcome-based Offerings at SIEMENS Mobility[15]

SIEMENS Mobility is now offering industrial products, such as railway rolling stock, as outcome-based services. Instead of selling rolling stock as a one-time transaction and providing complementary maintenance and repair services, the availability of rolling stock is guaranteed through the payment of a service fee. This business model has extensive implications for internal service provisioning. In the past, OEM costs related to MRO activities were billed to customers, which means that internal inefficiencies were charged to customers. As a consequence, OEMs had little incentive to make their MRO activities cost-efficient. But by offering availability and uninterrupted operations of trains, SIEMENS' customers are no longer billed for individual MRO activities. Thus, inefficient service activities now result in higher internal costs for SIEMENS and decreased margins. The flow of DDSs from digitized trains helped SIEMENS to increase internal efficiencies and enables it to offer a competitive outcome-based service.

Stage 6 Characteristics. Outcome-based offerings require an OEM to have a comprehensive digital infrastructure coupled with continuous streams of operational data (D1.2) from the installed product base. Based on advanced analytical models (D2.2) and the in-depth integration of business and customer information (D4.3), customers can be automatically billed based on actual product usage (D3.3). However, outcome-based

[14] For a more detailed understanding of the value concept in service literature, see Vargo, S. L. and Lusch, R. F. "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing* (68:1), 2004, pp. 1-17.

[15] More information can be found at http://www.mobility.siemens.com/mobility/global/en/services/Pages/services.aspx

offerings are a radical service innovation that requires careful planning by OEMs and will likely result in enormous organizational changes and requirements.

SIEMENS Mobility had to fully understand the cost and revenue drivers of its railway customers' businesses (D5.2) before it could devise an adequate outcome-based offering (D6.3). Product operational and billing information is now accessible in a standardized way via a digital platform (D7.3). In addition, SIEMENS Mobility had to comprehensively rethink the business model for its MRO activities.

Traditionally, customers have been billed for every service activity, resulting in more revenue for the OEM when its MRO activities are inefficient (e.g., an initial diagnosis visit and a second visit with the correct spare parts). Outcome-based offerings, however, guarantee product uptimes and availability in return for fixed-price service level agreements. This means that OEMs bear the costs of inefficient MRO activities and the consequences of breakdowns. Outcome-based offerings are therefore a strong driver for harnessing DDSs to increase the efficiency of traditional service activities and engineering ever-higher-quality products. Delivering business outcomes also promotes new partnerships between stakeholders in service ecosystems that holistically address customer needs. Hence, with pay-per-use or outcome-based offerings, the entire business model of OEMs is based on DDSs and industrial products that are augmented with digital technology.

SIEMENS achieved breakthroughs by successfully implementing an outcome-based business model in its Mobility division. thyssenkrupp, however, made a strategic decision to postpone implementing outcome-based offerings. The reason for this decision lies in the market characteristics and high margins of the MRO services it provides for the majority of its product portfolio, such as passenger and freight elevators, escalators, moving walkways, passenger boarding bridges and stair and platform lifts.

Guiding Principles and Actions for OEM Executives

Leveraging the DDSs flowing from digitized industrial products to create data-driven industrial services has far-reaching implications for OEMs. These services have the potential to radically transform value creation in the manufacturing industry. But the emerging opportunities, and their associated dependencies, pose strategic risks that create challenges for OEM executives. Based on what we learned from thyssenkrupp and SIEMENS, we have derived insights and identified the successful practices that OEM executives can use to harness DSSs in their industrial services businesses in an incremental and stepwise way. Table 3 summarizes our guiding principles and the actionable advice associated with each principle. The principles and actions are grouped under the three dimensions of the capability framework described earlier.

Guiding Principle	Actions
Digital Data Streams and Technology	
1. Digitize the installed product base in a modular way. Start with implementing foundational capabilities and incrementally extending them.	• Realize quick wins to generate initial operational impact. • Design foundational digital capabilities in a layered, modular and open way.
2. Prepare the information infrastructure to handle large data volumes.	• Modernize existing corporate network architecture and infrastructure early. • Invest in capabilities for storing and analyzing huge amounts of operational data.
Internal and Managerial Capabilities	
3. Foster interdisciplinary collaboration and acquire highly diverse skill sets.	• Attract and manage interdisciplinary skill sets and employees. • Establish an adequate organizational structure for collaboration across departments and disciplines.
4. Foster a pioneering spirit and digital culture, and encourage middle management to learn in "lighthouse" projects.	• Proclaim top management support and strategic relevance.
External Collaboration and Value Co-Creation	
5. Identify the firm's value proposition in the ecosystem and foster collaboration with external partners.	• Forge strategic partnerships. • Take account of customer needs and requirements when designing data-driven industrial services.
6. Understand the true value of DDSs as a resource for various internal and external stakeholders and in particular for customers.	• Understand your firm's business model and value proposition within the ecosystem.

Table 3. Guiding Principles and Actions for Successfully Harnessing DDSs

Digital Data Streams and Technology

Guiding Principle 1: Digitize the Installed Product Base in a Modular Way. Effectively leveraging DDSs in industrial services is an evolutionary transformation journey involving a stepwise implementation of services that fit into an OEM's organizational goals. It is not about turning on a switch and everything changes. Start by implementing foundational capabilities and incrementally extending them. The six service stages represent a typical, modular, step-by-step journey toward fully harnessing DDSs in industrial services. Executives, however, must focus on both gaining short-term quick wins and building up a sound foundational platform in the long term.

Action: Realize quick wins to generate initial operational impact. "Lighthouse" projects and prototypes can provide quick wins and help OEMs to rapidly learn about data-driven industrial services. Early attempts by thyssenkrupp to leverage operational product data in the context of engineering and R&D services (Stage 1) or triggering service activities in a reactive MRO business (Stage 2) are examples of quick wins achieved without having to implement a full-blown digital architecture. Early successes such as these will help OEMs to better understand the shift toward value-in-use offerings. Similarly, SIEMENS' achieved quick wins with its early data-driven service offerings, which were organized into "service lines" acting as autonomous profit centers that address specific customer needs. In line with these quick win experiences, thyssenkrupp set up a marketing campaign to communicate the early successes of its MAX initiative, emphasizing its benefits for global data-driven MRO activities.

Action: Design foundational digital capabilities in a layered, modular and open way. Executives must keep in mind that specific business requirements and needs change over time due to the generative capacity of digital technology. Besides implementing self-contained proof-of-concept projects, we recommend establishing timely operational visibility of product operations as a first strategic objective and as a strategic technology foundation for more sophisticated data-driven services. At later stages, however, unidirectional DDSs will not be sufficient to realize more complex services. Feedback and remote-control functionality is needed.

For example, thyssenkrupp's VISTA project focused on unidirectional transmission of predefined error codes, which were used to reactively trigger service activities. This approach limited the possibilities for leveraging the VISTA architecture because the system lacked usage information from "healthy" elevators.

Designing foundational digital capabilities in a layered, modular and open way enables OEMs to complement and round out existing capabilities to fully exploit further "smart" service opportunities at later stages of the digitization journey. Thus, OEMs should ensure that "lighthouse" projects are aligned with the overall digitization strategy and aim to build a modular, flexible and open technology foundation for the future development of data-driven industrial services.

Guiding Principle 2: Prepare the Information Infrastructure to Handle Large Data Volumes. DDSs are an essential resource for successfully managing innovative industrial services. Making this resource available for industrial services is a tremendous challenge in terms of transmitting, storing and analyzing the large amounts of data from DDSs.

Action: Modernize existing corporate network architecture and infrastructure early. When leveraging DDSs to create smart industrial services, CIOs must address any restrictions imposed by their existing IT infrastructures. An OEM's existing global corporate network and storage infrastructure is often not designed to continuously transmit streams of data from industrial products located worldwide and store the vast amounts of incoming data. For instance, thyssenkrupp's existing corporate network had limited bandwidths and was not designed to meet the requirements of transmitting DDSs from globally distributed manufacturing sites to the corporate headquarters in Essen, Germany. thyssenkrupp therefore had to embark on a "digital backbone" strategic project and had to centralize and harmonize its data centers.

The need for modernization is also driven by products installed in the field. Consider, for example, wind turbines or mining equipment, which often operate in remote locations with poor communications infrastructures. OEMs must identify intelligent approaches to exploit the available bandwidths in an optimal way.

Action: Invest in capabilities for storing and analyzing huge amounts of operational data. Another challenge is storing the large amounts of heterogeneous data that stems from millions and millions of sensors embedded in industrial products. Traditional database technologies, such as relational databases, are limited in terms of the data volumes they can handle. So-called "NoSQL" database technology allows highly flexible data modelling and is much more scalable than traditional database technology. CIOs in OEMs must select technology partners to implement this type of database technology and build up the internal skills and competencies that will enable them to communicate as equals with their technology partners. Both thyssenkrupp and SIEMENS have teamed up with technology partners to establish highly flexible and scalable digital platforms that are tailored to their particular needs. As the core of a sound information infrastructure, the platforms provide them with the flexibility to handle future requirements for data-driven industrial services.

DDSs are becoming the new standard for operating and servicing industrial products. As OEMs and their partners in the ecosystem provide additional digital services, the volume of data from DDSs will increase further and result in additional technical requirements. OEMs need to evaluate whether they can develop a platform to provide a foundation for digital service offerings themselves or should team up with a technology partner.

Internal and Managerial Capabilities

Guiding Principle 3: Foster Interdisciplinary Collaboration and Acquire Highly Diverse Skill Sets.

Action: Attract and manage interdisciplinary skill sets and employees. To offer data-driven industrial services that are consistent with organizational goals, OEMs need a workforce with a highly diverse skill set and truly distinctive backgrounds. When trying to recruit knowledge workers and highly skilled experts for analytics and data science roles, OEMs compete directly with large software organizations. Experts in these fields will often first consider working for innovative software companies. OEMs should consider hosting internal and external hackathons and other tech-related events to raise awareness among these types of experts of how innovative and attractive their organization is.

When SIEMENS started to offer digital services, such as plant data services, energy efficiency services and process efficiency services (Stage 4), it created a single organizational function staffed by an interdisciplinary team of digitization and service experts. Interdisciplinary collaboration was raised to a new level when SIEMENS decided to build the MindSphere platform. SIEMENS collaborated with SAP as an external strategic partner to co-create value. However, jobs that require lower skill profiles, such as field service technicians, will gradually be replaced by automated digital technology. In particular, repetitive roles and activities will be affected by this trend.

Action: Establish an adequate organizational structure for collaboration across departments and disciplines. To develop products and services that meet customers' needs and leverage digital technology, departments with completely different backgrounds will have to collaborate at an operational level. IT experts will have to collaborate with product engineers as they focus on generating relevant information for a data-driven service business based on sensor technology and data originating from product control units. However, traditional and established organizational structures can be obstacles to the collaboration required in the product and service design process. An effective way to break away from silo thinking is to spin off organizational units. Executives in more traditional manufacturing organizations might consider establishing spin-offs and locating them in areas already populated by high-tech businesses as a way of attracting talented innovators and programmers. In particular, this approach might help circumvent complicated corporate decision-making processes and restrictive policies.

CIOs and executives in OEMs must decide how they want to define the roles and organizational structures that are responsible for operational product data. Decisions have to be made on whether to set up a centralized or decentralized organizational structure, on data ownership and on related governance mechanisms. Particularly in large organizations, individual business units often want a high level of autonomy in managing and leveraging the DDSs in their own service businesses. Corporate management in OEMs might consider whether to introduce new roles, such as chief digital officer (CDO), to clarify how the organization deals with digitization initiatives.[16] To facilitate the implementation of data-driven services and products, thyssenkrupp established a corporate digitization office that centrally monitored, orchestrated and managed the diverse strategic initiatives and "lighthouse" projects.

Guiding Principle 4: Foster a Pioneering Spirit and Digital Culture, and Encourage Middle Management to Learn in "Lighthouse" Projects.

Action: Proclaim top management support and strategic relevance. Because of the need for interdisciplinary collaboration, top management support is crucial for the successful implementation of innovative data-driven industrial services. OEM executives need to generate awareness of digitization opportunities and the importance of digital technology for the competitiveness of the organization. Awareness can be generated in various ways.

For instance, thyssenkrupp has initiated an annual global two-day executive event known as a "Digitization Forum," which brings together the top 100 senior managers and CEOs and CIOs of the individual thyssenkrupp businesses. Keynotes from thyssenkrupp's CEO, as well as external speakers from software and technology organizations, create the momentum for further digitization efforts. The forum is designed to create awareness among thyssenkrupp's top management of the digitization of the business, to share success stories, identify opportunities for digitization, define and communicate group-wide cornerstones of the digitization strategy and inculcate the mindset necessary to increase momentum. thyssenkrupp has also established the "Innovation

[16] For further information on how digitization of products changes internal organizational structures, see Porter, M. E. and Heppelmann, J. E. "How Smart, Connected Products Are Transforming Companies," *Harvard Business Review* (93:10), 2015, pp. 96-114.

Garage," which brings together interdisciplinary employees from all organizational levels on an equal footing. This format helps spread a pioneering spirit and provides a platform that encourages innovation away from day-to-day duties.[17]

In a similar fashion, SIEMENS established "next47" as a dedicated organizational entity for innovation and as a catalyst for an "open start-up culture."[18] SIEMENS employees are encouraged to create spin-offs to realize their own business ideas. Innovation is a key pillar of SIEMENS' new vision announced at the end of 2015.[19] Digitization, innovation and fostering a pioneering spirit and culture as key elements of the corporate strategy provide a starting point for establishing an adequate organizational foundation. A shared vision that can be operationalized by means of a high-level digitization roadmap helps middle management make the right decisions on how to achieve the organization's overarching goal.

External Collaboration and Value Co-Creation

Guiding Principle 5: Identify the Firm's Value Proposition in the Ecosystem and Foster Collaboration with External Partners.

Action: Forge strategic partnerships. Partnering with external organizations allows OEMs to set up the digital infrastructure needed to implement industrial services that address the needs of potential customers. Partners create an ecosystem with digital service platforms as a shared foundation for innovation. These platforms are, in effect, marketplaces that enable smaller, niche firms to offer highly specialized supporting services. An example would be data analytics for rotating industrial products (e.g., engines, generators or wind turbines) based on a fast Fourier transform algorithm.[20] These supporting services can be used as modular elements of an OEM's data-driven industrial services offerings.

---

[17] For more information on the Innovation Garage concept, see http://www.thyssenkrupp-components-technology.com/en/innovation/innovation-garage/.

[18] For more information, see www.siemens.com/press/next47; and http://www.next47.com.

[19] For more information on SIEMENS' innovation strategy, see https://www.siemens.com/about/pool/strategy/siemens-strategy-overview.pdf.

[20] For further information on vibration analysis of industrial products, see Randall, R. B. *Vibration-based condition monitoring: industrial, aerospace and automotive applications*, John Wiley & Sons 2011.

Because various stakeholders are involved in value co-creation, the service ecosystem becomes extremely complex and interwoven. To stand out from the crowd, an OEM needs a unique value proposition in the ecosystem to ensure a sustainable competitive advantage.

OEM executives must decide whether to enter strategic partnerships with existing platform operators or set up their own platform. However, setting up a digital architecture is not a core competency of most industrial OEMs. We therefore recommend partnering with experienced players in the software industry. For instance, both thyssenkrupp and SIEMENS decided to team up with experienced technology partners. They recognized that a competent software partner is needed to rapidly build generative platform capabilities as the technology basis for capturing, storing and analyzing DDSs in a standardized, cost-efficient and highly scalable way.

Due to the diversity of its product portfolio, thyssenkrupp aims to adapt and customize the existing digital platforms of various software companies, while also taking account of the specific requirements of its highly heterogeneous business areas. For example, the elevator division leverages Microsoft's Azure platform to generate insights from the DDSs transmitted by digitized elevators. thyssenkrupp chose this approach because of Azure's sophisticated machine learning capabilities. In contrast, SIEMENS chose to leverage SAP HANA Cloud Platform as the technology basis for its MindSphere digital platform, which is designed to address all of its business needs in a powerful and highly flexible way.[21] SIEMENS positions MindSphere as an open platform offering, with the aim of attracting other OEMs or industrial organizations to use it. OEMs also have to forge strong partnerships with electronic equipment providers of the sensors, actuators and connectivity needed to augment their products.

From the above, it is clear that, to provide data-driven industrial services, OEMs need access to considerable know-how in multiple areas of digital technology. To create the solutions demanded by their customers, they must collaborate with partners in an extensive ecosystem. As data-driven industrial services become more complex, close interdisciplinary collaboration across organizational and industry boundaries is becoming more and more important for delivering comprehensive value propositions.

[21] SAP HANA Cloud Platform is an open platform-as-a-service providing unique in-memory database and business application services developed and marketed by SAP SE.

Action: Take account of customer needs and requirements when designing data-driven industrial services. When designing innovative service offerings, customer needs have to be taken into account. Co-innovation workshops with customer representatives help identify those needs and clarify the OEM's vision for data-driven services, and thus generate a common understanding of the technology cornerstones of potential future services.

Guiding Principle 6: Understand the True Value of DDSs as a Relevant Resource for Various Internal and External Stakeholders and Customers.

Action: Understand your firm's business model and value proposition within the ecosystem. Although the lifecycles of industrial products often span decades, digitization of the installed product base is more relevant than one might assume. The industrial products market is changing rapidly, and within a couple of years it might be impossible to efficiently and effectively operate and service industrial equipment without using DDSs. Organizations, however, are often wary of sharing operational data with their partners—even if not doing so has a negative effect on productivity. The industrial services ecosystem is characterized by a high level of intricacy in terms of service processes and involves many stakeholders, including external partners. To leverage the new technology-based capabilities of "smart" and connected industrial equipment effectively, OEMs must have an end-to-end perspective of service processes. To maximize benefits from the new opportunities, OEM executives should focus on the added value of DDSs in service processes and take into account the information needs of all stakeholders.

For example, in all its digitization efforts SIEMENS leverages the methodological input of a dedicated in-house consulting team when designing the business model and value proposition for its internal and external customers and initiatives. New digital services that draw on DDSs (Stage 3) are tested with internal and external lead customers to ensure that they provide value.

Concluding Comments

Value creation in the manufacturing industry is shifting from goods-dominant product sales toward flexible service-dominant offerings that will ultimately be outcome based. As an example, a wind turbine manufacturer no longer just sells turbines to wind farm operators and offers ad hoc maintenance and repair services. Instead, the manufacturer offers a service that makes it responsible for smooth operations of the wind farm. Similarly, a forklift manufacturer no longer just sells and maintains forklifts. Instead, it offers a service for moving the customer's inventory and for the smooth operation of the customer's intra-logistics processes. Likewise, industrial OEMs like thyssenkrupp and SIEMENS increasingly compete on their ability to deliver measurable results that add value for their customers. But offering industrial services such as these requires the seamless interplay of physical mechanical engineering, electronics, human workforce and software. All of these need to be managed and orchestrated to effectively harness the emerging opportunities of digital technology for the industrial services business.

Executives in manufacturing companies need to understand the new mechanics of value creation in the digital age and adapt them to the specific service context of their organizations. By harnessing the DDSs that flow from digitized industrial products, OEMs can create innovative new service offerings. OEMs therefore need to embark on a digital transformation journey.

As a guide to this journey, we have presented a capability framework and described the resulting six strategic data-driven industrial service stages. Understanding the framework and stages will help OEM executives make sound goal-oriented decisions to harness DDSs on the individual journeys of their organizations.

Based on the learnings from thyssenkrupp and SIEMENS, we have described the actions OEMs can take:

- *Digital Data Streams and Technology:* Lay the technical foundation by digitizing the installed product base in a modular way, create a digital infrastructure that can handle large amounts of operational data, and build powerful and open digital architectures.
- *Internal and Managerial Capabilities:* Establish the organizational basis for interdisciplinary collaboration of diverse skill sets, and foster a pioneering spirit through "lighthouse" projects.
- *External Collaboration and Value Co-creation:* Understand the need to re-orient the organization's value proposition and forge strategic partnerships with technology providers.

Digital transformation will have far-reaching consequences for the manufacturing industry. OEMs will be able to diversify their product and service offerings by integrating their domain knowledge into digital "behind-the-scenes" services such as data collection and connectivity services, and industry-specific analytical services that can be offered through digital platforms. Eventually, modular digital service ecosystems with highly specialized niche players will emerge. thyssenkrupp and SIEMENS, as two of the largest industrial multinational conglomerates, are well into their digitization journeys. The ultimate transition to outcome-based business models, however, will take many years because there are many technical and managerial challenges that have to be overcome.

Appendix: Research Method

Starting in early 2014, we studied the journeys of thyssenkrupp and SIEMENS, the two largest industrial product manufacturers in Germany, toward leveraging digitized industrial products in their product and service business. We selected these two organizations based on (1) their existing and planned digitization efforts and resulting perceived digital maturity, (2) the importance of their industrial services business and (3) the diversity and scale of their operations.

Our research used multiple methods, such as interviews with experts, analysis of internal documents and publicly available information, and focus group workshops, to obtain in-depth insights on the digitization efforts and how the DDSs from digitized products were used in data-driven industrial service offerings over time. We also closely collaborated with both companies on their servitization and digitization projects.

Initially, we conducted 19 semi-structured interviews over two years with executives and senior managers from the IT department and business divisions of both companies. The interviewees provided an international perspective from various locations, such as Erlangen, Essen, Dortmund, Stuttgart, Madrid, Cincinnati, Seattle, Dallas, Seoul and Shanghai. Interviews were recorded, transcribed and analyzed using a computer-supported qualitative data analysis tool following an interwoven three-stage process of open, axial and selective coding.[22] A combination of affordance theory and socio-technical systems theory was used to take account of both technological and social aspects of data-driven services as well as the similarities and differences of how the two case organizations have harnessed DDSs over time.[23]

Based on the learnings from thyssenkrupp and SIEMENS, we identified six data-driven industrial service stages and formed an evolutionary view of the journey toward harnessing DDSs for providing these services. We adapted the well-established approach

[22] Corbin, J. and Strauss, A. "Grounded Theory Research: Procedures, Canons, and Evaluative Criteria," *Qualitative Sociology* (13:1), 1990, p. 3; Strauss, A. and Corbin, J. M. *Grounded Theory in Practice*, Sage Publications, 1997.

[23] Gibson, J. J. *The Ecological Approach to Visual Perception*, Psychology Press, 1986; Majchrzak, A. and Markus, M. L. "Technology Affordances and Constraints in Management Information Systems (MIS)," in *Encyclopedia of Management Theory*, E. Kessler (ed.), Sage Publications, 2013, pp. 832-836..

for taxonomy building suggested by Nickerson et al.[24,25] to iteratively design and evaluate the capability framework presented in this article. This approach involved both conceptual-to-empirical and empirical-to-conceptual design of the framework. From a literature review (conceptual-to-empirical) and the experiences of thyssenkrupp and SIEMENS (empirical-to-conceptual), we identified the industrial services that harness DDSs. The dimensions of the capability framework were iteratively refined, based on insights from several focus group workshops with executives and on our evaluation of service innovation projects within the two organizations.

Additional 13 recorded and transcribed interviews, as well as focus group workshops with executives from other organizations in the manufacturing industry, allowed us to corroborate and evaluate the six service stages. For instance, we integrated an early and rather specific service stage of "controlling and managing industrial products remotely" into the broader service stage called "digital services for data-driven product operations." This modification was necessary because controlling and managing industrial products remotely can be considered a specific service that cannot be realized in all industries.

[24] Nickerson, R. C., Varshney, U. and Muntermann, J. "A Method for Taxonomy Development and Its Application in Information Systems," *European Journal of Information Systems* (22:3), 2013, pp. 336-359; Nickerson, R., Varshney, U., Muntermann, J. and Isaac, H. "Taxonomy Development in Information Systems: Developing a Taxonomy of Mobile Applications," in *Proceedings of the 17th European Conference on Information Systems (ECIS),* Verona, Italy, 2009.

[25] Bostrom, R. P. and Heinen, J. S. "MIS Problems and Failures: A Socio-Technical Perspective Part I: The Causes," *MIS Quarterly* (1:3), 1977, pp. 17-32.

F – **List of Publications**

Publications in chronological order from new to old; official order of authors that indicates the contributions of the authors; all entries are blind or double-blind peer-reviewed; rankings according to

(1) VHB-JOURQUAL3 (http://vhbonline.org/VHB4you/jourqual/vhb-jourqual-3/gesamtliste/) and
(2) 'WI-Orientierungsliste' (http://wi.vhbonline.org/zeitschriftenrankings/)

Manuscripts under review and before publication

Meta-data of publication	*Rankings*[1]
Herterich, M.M., vom Brocke, J., and Brenner, W. (under review). "Service Innovation in a Material World – Exploring How Digitized Products Afford Smart Service Systems in Industrial Service Ecosystems". *Journal of Service Research*.	VHB: A WI: n.a.
Dremel, C., **Herterich, M.M.**, Wulf, J., Spottke, B. (2017, accepted for publication). "Actualizing Affordances: A Socio-Technical Perspective on Big Data Analytics in the Automotive Sector". In: *Proceedings of the 38th International Conference on Information Systems (ICIS).* Seoul, South Korea.	VHB: A WI: A
Holler, M., **Herterich, M.M.**, Dremel, C., Uebernickel, F., Brenner, W. (2017, conditionally accepted). "Towards a Method Compendium for the Development of Industrial Digitized Products - Findings from a Case Study". *International Journal of Product Lifecycle Management.*	VHB: C WI: n.a.

Published journal articles and conference proceedings

Dremel, C., **Herterich, M.M.**, Waizmann, J.-C., Brenner, W. & Wulf, J. (2017). "How AUDI AG Established Big Data Analytics in Its Digital Transformation". *MIS Quarterly Executive*. Vol. 16 No. 2.	VHB: B WI: B

[1] Rankings according to (1) VHB-JOURQUAL3 Ranking (vhbonline.org/VHB4you/jourqual/vhb-jourqual-3/gesamtliste/) and (2) 'WI-Orientierungsliste' (http://wi.vhbonline.org/zeitschriftenrankings/)

Herterich, M.M. (2017). "On the Design of Digitized Industrial Products as Key Resources of Service Platforms for Industrial Service Innovation. In: *Lecture Notes in Computer Science (LNCS), Proceedings of the 12th International Conference on Design Science Research in Information Systems and Technology (DESRIST).* Karlsruhe, Germany. — VHB: C, WI: B

Herterich, M.M. and Mikusz, M. (2016). "Looking for a Few Good Concepts and Theories for Digitized Artifacts and Digital Innovation in a Material World". Completed Research Paper In: *Proceedings of the 37th International Conference on Information Systems (ICIS).* Dublin, Ireland. — VHB: A, WI: A

Herterich, M.M., Uebernickel, F. and Brenner, W. (2016). "Stepwise Evolution of Capabilities for Harnessing Digital Data Streams in Data-Driven Industrial Services". *MIS Quarterly Executive*. Vol. 15 No. 4. — VHB: B, WI: B

Dremel, C. and **Herterich, M.M.** (2016). "Digitale Cloud-Plattformen als Enabler zur analytischen Nutzung von operativen Produktdaten im Maschinen- und Anlagenbau". *HMD Praxis der Wirtschaftsinformatik*. Vol. 53 No. 2 — VHB: D, WI: B

Herterich, M.M., Eck, A. and Uebernickel, F. (2016). "Exploring How Digitized Products Enable Industrial Service Innovation - An Affordance Perspective". Completed Research Paper In: *Proceedings of the 24rd European Conference on Information Systems (ECIS)*. Istanbul, Turkey. — VHB: B, WI: A

Herterich, M.M., Buehnen, T., Uebernickel, F. and Brenner, W. (2016). "A Taxonomy of Industrial Service Systems Enabled by Digital Product Innovation". Completed Research Paper In: *Proceedings of the 49st Annual Hawaii International Conference on System Sciences*. Kauai, USA. — VHB: C, WI: B

Herterich, M.M., Uebernickel, F. and Brenner, W. (2015). "Empowering Technical Customer Service by Cyber-Physical Industrial Equipment: Exploring Rationales, Opportunities, and Impediments". Completed Research Paper In: *Proceedings of the 19th Pacific Asia Conference on Information System (PACIS)*. Singapore. — VHB: C, WI: B

Herterich, M.M, Uebernickel, F. and Brenner, W. (2015). "Nutzenpotentiale cyber-physischer Systeme für industrielle Dienstleistungen 4.0". *HMD Praxis der Wirtschaftsinformatik*. Vol. 52 No. 5 pp. 665–680.[2] — VHB: D, WI: B

[2] This paper was awarded with the 'HMD Best Paper Award 2015' and was published as a book in the *Springer essential* series.

Herterich, M.M., Holler, M., Uebernickel, F. and Brenner, W. (2015). "Understanding the Business Value: Towards a Taxonomy of Industrial Use Scenarios enabled by Cyber-Physical Systems in the Equipment Manufacturing Industry". In: *Proceedings of the International Conference on Information Resources Management (CONF-IRM).* Ottawa, Canada.	n. a.
Herterich, M.M., Uebernickel, F. and Brenner, W. (2015). "The Impact of Cyber-physical Systems on Industrial Services in Manufacturing". *Procedia CIRP 7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business*. Vol. 30, pp. 323–328.	n. a.
Herterich, M.M., Peters, C., Uebernickel, F., Brenner, W. and Neff, A. (2015). "Mobile Work Support for Field Service: A Literature Review and Directions for Future Research". In: *Proceedings of the 12th International Conference on Wirtschaftsinformatik (WI)*. Osnabrück, Germany.	VHB: C WI: A
Neff, A., Uebernickel, F., Brenner, W., Lingemann, S. and **Herterich, M.M**. (2014). "Towards a Functional Reference Model for Service Planning and Execution in the Heavy Equipment Manufacturing Industry". In: *Proceedings of the 11th European, Mediterranean & Middle Eastern Conference on Information Systems (EMCIS).* Doha, Qatar.[3]	n. a.

Books or book chapters

Herterich, M.M., Uebernickel, F. and Brenner, W. (2016). *Industrielle Dienstleistungen 4.0*. essentials. Springer Fachmedien Wiesbaden, Germany.	VHB: D WI: B

Working paper

Herterich, M.M., Uebernickel, F. and Brenner, W. (2015). "The Next Wave of Service Innovation: How Cyber-Physical Systems can be Leveraged for Effective Industrial Equipment Operations and Empower Industrial Service". *Working Paper Series on Research in Information Systems Management and Business Innovation*. No. 3.	n. a.

[3] This paper was awarded with the 'EMCIS 2014 Best Paper Award'

Presentations

Herterich, M.M. (2014). *Learning to Leverage Design Thinking in the Context of Service Engineering and Information Systems - A Case Study*. Presented at the Pre-ECIS 2014 Workshop on Design Thinking in Business Information Systems. Tel Aviv, Israel.	n. a.

G – **Curriculum Vitae**

Personal Data

Place of birth	Bad Friedrichshall, Germany
Nationality	German

Academic Education

2017 - 2017	Stanford University – Visiting Scholar at Center for Design Research (CDR); Stanford, CA (USA)
2014 - 2017	University of St.Gallen (HSG) – PhD studies in Management, Specialization: Business Innovation at Institute of Information Management (IWI-HSG); St.Gallen (Switzerland)
2011 - 2014	University of Mannheim – Master of Science (M.Sc.) in Management Information Systems; Mannheim (Germany)
2012 - 2013	University of Florida – Semester Abroad at Warrington College of Business Administration; Gainesville, FL (USA)
2008 - 2011	Duale Hochschule Baden-Württemberg (DHBW) – Bachelor of Science (B.Sc.) in Business Informatics; Karlsruhe (Germany)
1999 - 2008	Friedrich-von-Alberti-Gymnasium – A-Levels; Bad Friedrichshall (Germany)

Employment

2014 – 2017	Institute of Information Management (IWI-HSG), Competence Center Industrial Services and Enterprise Systems – Research Associate; St.Gallen (Switzerland)
2013 – 2014	SAP SE – HANA Enterprise Cloud, Virtualization & Cloud – Working Student; Walldorf (Germany)
2013 - 2013	Deloitte Consulting GmbH – Intern; Stuttgart, Bonn (Germany)
2012 - 2013	Savero GbR – Founder and Director; Mannheim (Germany)
2012 - 2012	Institute for Enterprise Systems (InES), University of Mannheim – Assistant Scholar; Mannheim (Germany)
2011 – 2012	EnBW Energie Baden-Württemberg AG, Operations-Strategy & Steering – Working Student; Karlsruhe (Germany)
2009 – 2011	EnBW Energie Baden-Württemberg AG – Dual Student; Karlsruhe, Stuttgart (Germany), Budapest (Hungary)