Digital Transformation in the Manufacturing Industry: Business Models and Smart Service Systems

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Für meine Familie.

Abstract

The digital transformation enables innovative business models and smart services, i.e. individual services that are based on data analyses in real-time as well as information and communications technology. Smart services are not only a theoretical construct but are also highly relevant in practice. Nine research questions are answered, all related to aspects of smart services and corresponding business models. The dissertation proceeds from a general overview, over the topic of installed base management as precondition for many smart services in the manufacturing industry, towards exemplary applications in form of predictive maintenance activities. A comprehensive overview is provided about smart service research and research gaps are presented that are not yet closed. It is shown how a business model can be developed in practice. A closer look is taken on installed base management. Installed base data combined with condition monitoring data leads to digital twins, i.e. dynamic models of machines including all components, their current conditions, applications and interaction with the environment. Design principles for an information architecture for installed base management and its application within a use case in the manufacturing industry indicate how digital twins can be structured. In this context, predictive maintenance services are taken for the purpose of concretization. It is looked at state oriented maintenance planning and optimized spare parts inventory as exemplary approaches for smart services that contribute to high machine availability. Taxonomy of predictive maintenance business models shows their diversity. It is viewed on the named topics both from theoretical and practical viewpoints, focusing on the manufacturing industry. Established research methods are used to ensure academic rigor. Practical problems are considered to guarantee practical relevance. A research project as background and the resulting collaboration with different experts from several companies also contribute to that. The dissertation provides a comprehensive overview of smart service topics and innovative business models for the manufacturing industry, enabled by the digital transformation. It contributes to a better understanding of smart services in theory and practice and emphasizes the importance of innovative business models in the manufacturing industry.

Keywords: Smart service, Business model, Value network, Value co-creation, Availability orientation, Installed base management, Digital twin, Predictive maintenance

Die digitale Transformation ermöglicht innovative Geschäftsmodelle und Smart Services, d.h. individuelle Services, die auf Datenanalysen in Echtzeit sowie auf Informations- und Kommunikationstechnologie basieren. Smart Services sind nicht nur ein theoretisches Konstrukt, sondern auch in der Praxis sehr relevant. Neun Forschungsfragen werden beantwortet, die sich alle auf Aspekte von Smart Services und dazugehörige Geschäftsmodelle beziehen. Die Dissertation geht von einem allgemeinen Überblick, über Installed Base Management als Voraussetzung für verschiedene Smart Services in der Fertigungsindustrie, hin zu Anwendungen in Form von vorbeugenden Instandhaltungsaktivitäten. Es wird ein umfassender Überblick über die Smart-Service-Forschung gegeben und Forschungslücken präsentiert, die bisher noch nicht geschlossen wurden. Es wird gezeigt, wie ein Geschäftsmodell in der Praxis entwickelt werden kann. Installed Base Management wird genauer betrachtet. Installed-Base-Daten kombiniert mit Zustandsdaten führen zu digitalen Zwillingen, d.h. dynamischen Modellen von Maschinen, einschließlich aller Komponenten, deren aktuelle Zustände, Anwendungen und Zusammenspiel mit der Umgebung. Gestaltungsprinzipien für eine Informationsarchitektur für Installed Base Mangement und die Anwendung in einem Use Case in der Fertigungsindustrie zeigen auf, wie digitale Zwillinge strukturiert werden können. In diesem Zusammenhang werden vorbeugende Wartungsdienste zur Konkretisierung herangezogen. Als beispielhafte Ansätze für Smart Services, die zu einer hohen Maschinenverfügbarkeit beitragen, wird die zustandsorientierte Instandhaltungsplanung und die optimierte Ersatzteilhaltung betrachtet. Die Taxonomie von Geschäftsmodellen für vorausschauende Instandhaltung zeigt die bestehende Vielfalt. Die genannten Themen werden sowohl aus theoretischer als auch aus praktischer Sicht betrachtet, wobei der Schwerpunkt auf der Fertigungsindustrie liegt. Zur Sicherstellung wissenschaftlicher Strenge werden etablierte Forschungsmethoden genutzt. Praktische Probleme werden betrachtet, um die praktische Relevanz sicherzustellen. Dazu tragen ein Forschungsprojekt und die daraus resultierende Zusammenarbeit mit verschiedenen Experten aus mehreren Unternehmen bei. Die Dissertation bietet einen umfassenden Überblick über Smart-Service-Themen und innovative Geschäftsmodelle für die Fertigungsindustrie, die durch die digitale Transformation ermöglicht werden. Sie trägt zu einem besseren Verständnis von Smart Services in Theorie und Praxis bei und unterstreicht die Bedeutung innovativer Geschäftsmodelle in der Fertigungsindustrie.

Management Summary

Nowadays, customers are more interested in solutions than in products. The digital transformation supports this demand. Smart services and innovative business models enable to satisfy individual, continually changing needs. Looking at the manufacturing industry, the digital transformation enables to realize novel business models that contribute to high machine availability. The objective of this dissertation is to provide a comprehensive insight in the topics of smart services and innovative business models enabled by the digital transformation. The main part of the dissertation is divided into three parts, going from the general to the specific. Within the first part, general topics concerning smart services are discussed that are mostly relevant for all types of smart services, independent from the considered industry. A comprehensive overview of the current state of smart service research including research gaps forms the entrance for further investigations. In the second part, it is focused on the manufacturing industry. New smart services and innovative business models in the manufacturing industry mostly base on digital twins. This applies especially for services that provide some kind of guaranteed machine availability. The installed base includes all components of a machine, their production processes and application. Data and information from different systems feed the installed base management system (IBMS). In addition to installed base data, digital twins also include condition monitoring data, mainly sensor data. The third part of the main part looks at a common type of smart service in the manufacturing industry: predictive maintenance. Thereby, it is exemplified how digital twins can be used for concrete smart services.

In order to provide a comprehensive overview of smart services and their current state of research, at the beginning a systematic literature review is performed (see Chapter 2.1). Eight different databases are considered to identify literature that focuses on smart services. In the publication Dreyer et al. (2019b) all publications are included that were published until the end of 2016. For this dissertation, the literature search is updated and the publication years 2017 and 2018 are also included. All articles that are identified to be relevant are categorized in two different dimensions: topic and lifecycle phase. In total, thirteen different topics within the field of smart service research are identified. These topics are not predefined but derived during the literature analysis. The Information Technology Infrastructure Library (ITIL) worked out a concept for a service lifecycle that contains five

phases in the current version from 2011. This framework is adapted and used for smart services. Therefore, each publication is analyzed regarding their covered phases of the lifecycle, that are smart service strategy, smart service design, smart service transition, smart service operation and continual smart service improvement. Each publication is assigned to at least one topic and one lifecycle phase. The analysis results are used to develop a heat map that shows the research intensity in the different topics, considering the different lifecycle phases (Figure 1). Thereby, the smart service lifecycle phases form the x-axis and the topics the y-axis.

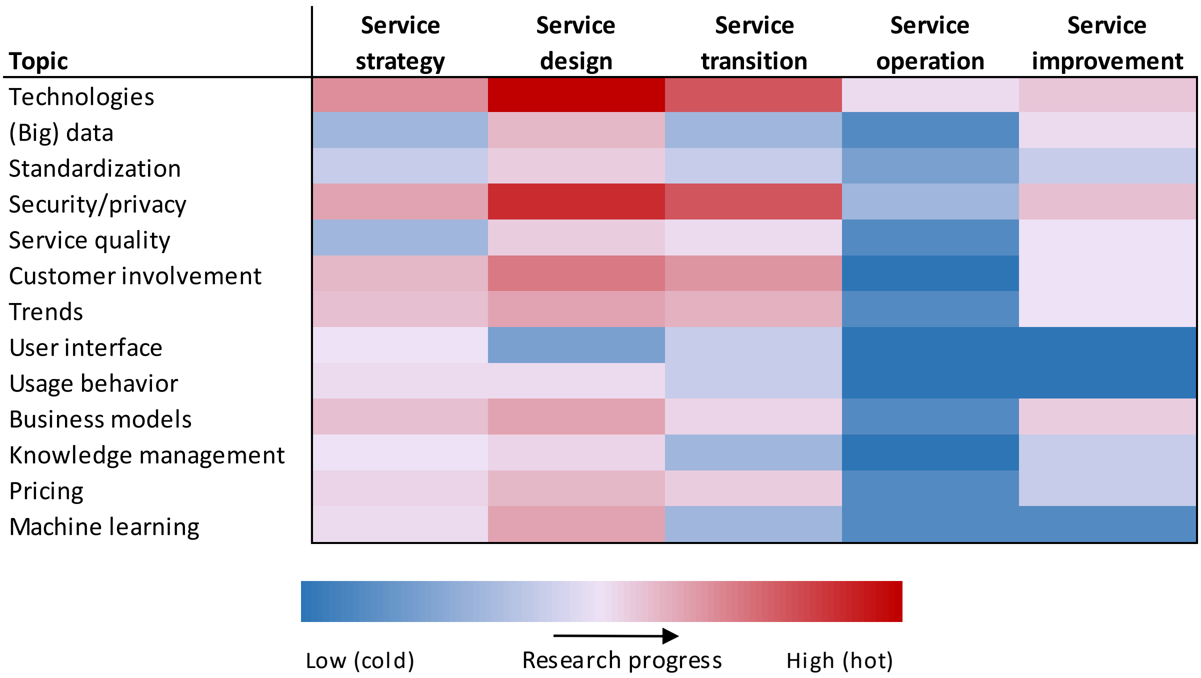

Figure 1. Heat map summarizing the research intensity

On the one hand, the heat map shows that researchers mostly concentrate on a few topics within the field of smart services. It can be seen that technologies as well as security/privacy are the topics that are mainly considered. On the other hand, potential research gaps are revealed. Economic aspects such as business models and pricing strategies are treated just as little as machine learning and knowledge management. Looking at the smart service lifecycle phases, the operation phase is nearly neglected when researching smart services. It is noticeable that the customer is not as much in focus as expected. In the literature, it is undisputed that the customer plays an essential role for relevant and successful smart services. But this is not reflected in the literature. The identification of the role of the customer and how to integrate him/her in all phases of the lifecycle is only one opportunity for further research. Looking at the customer's behavior and how to use the findings to continually improve smart services is another research gap.

As smart service business models are mainly not focused when looking at smart service research, an exemplary development of an availability-oriented business model shows how such a business model can be realized in practice (see Chapter 2.2). An existing framework is used for a systematic development. Business model ideas are collected in focus group discussions with participants from different companies. The necessary value network is derived and target groups are identified. With the description of possible scenarios, the business model ideas are more and more concretized. In the last step, a modeling framework is derived and adapted to the business model. The framework contains four abstraction levels, including context level, functional level, logical level and physical level.

Apart from the business model topic, the heat map shows that knowledge management is rarely considered in the context of smart services. Therefore, a literature review is conducted to identify requirements for knowledge management for smart services. As knowledge management is mostly not explicitly named, implicitly named requirements when describing a smart service strategy or design are also considered. Knowledge management is already used in practice for other application scenarios. This is why it is focused on characteristics that are different for smart services or particularly important to realize successful smart services. Nine characteristics are identified and each of them could exactly be assigned to one of the three following categories: input/output, structure and reliability. Depending on the specific smart service, the input and the output can range from simple to highly complex. The structure of the management system can be central, where all knowledge is added, maintained and consolidated at a central point, e.g., in a cloud, or decentralized. Solutions between these two extremes are also possible. The required reliability also depends on the smart services for which the knowledge management system should serve. Although the highest possible reliability of the system seems to be the best solution, the high costs must be considered and a balance must be found. The findings are depicted within a reference model (Figure 2). Every point in the three-dimensional space of the cube describes one possible realization of a knowledge management system for smart services. Thereby, the diversity of knowledge management for smart services is shown. Design principles for knowledge management systems for smart services ensure practical feasibility.

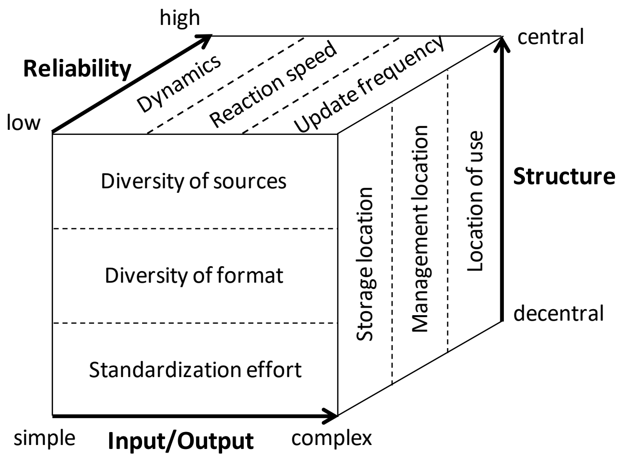

Figure 2. Cube model illustrating the diversity of knowledge management for smart services.

The development of business models and requirements for knowledge management systems mainly refer to the strategy and design phases. But the smart service transition phase is also important. This is the reason why critical success factors are identified for introducing smart services. In the first step, a literature review is conducted. Thereby, ten different success factors are identified. These success factors form the basis for interviews with smart service experts from different companies. These experts discuss the critical success factors and further name five additional ones. Although there are success factors that are only named by one or two experts, one success factor is added by most of the experts: consideration of the market. Different aspects are included in this critical success factor. A comprehensive market analysis is necessary. As smart services are often provided worldwide, a suitable strategy must be investigated. Cultural differences are another aspect that relates to the fact that smart services are provided worldwide. Depending on the culture, the best market entrance strategy differs. Marketing activities must be adapted accordingly for a successful introduction of a smart service.

After investigating general topics related to smart services, it is focused on the manufacturing industry. Novel smart services and business models mainly contribute to the most important demand of the customers in that industry: high machine availability. Installed base management and the corresponding digital twin play a central role to be able to contribute to this requirement. Therefore, an information architecture for installed base management is developed. In accordance with the action design research (ADR) approach, a practical problem in a company is solved using academic methodology. Requirements for an information architecture that are named by the target company are collected and added with requirements collected from the literature. A prototype is designed and afterwards discussed with experts. The prototype is adapted accordingly. This is continued until the final version is reached. Within an applicability check, the installed base of a machine is digitalized using the developed information architecture. Finally, design principles are worked out that help practitioners to apply the information architecture to their needs. Thereby, an important design principle is the consequent service orientation. This means to remain flexible and to be able to adapt the information architecture continually, according to the requirements. It should be possible to integrate tools that are necessary for individualized smart services. Real-time data are also necessary for nearly all types of smart services in the manufacturing industry. Therefore, the information architecture should support data handling in real-time.

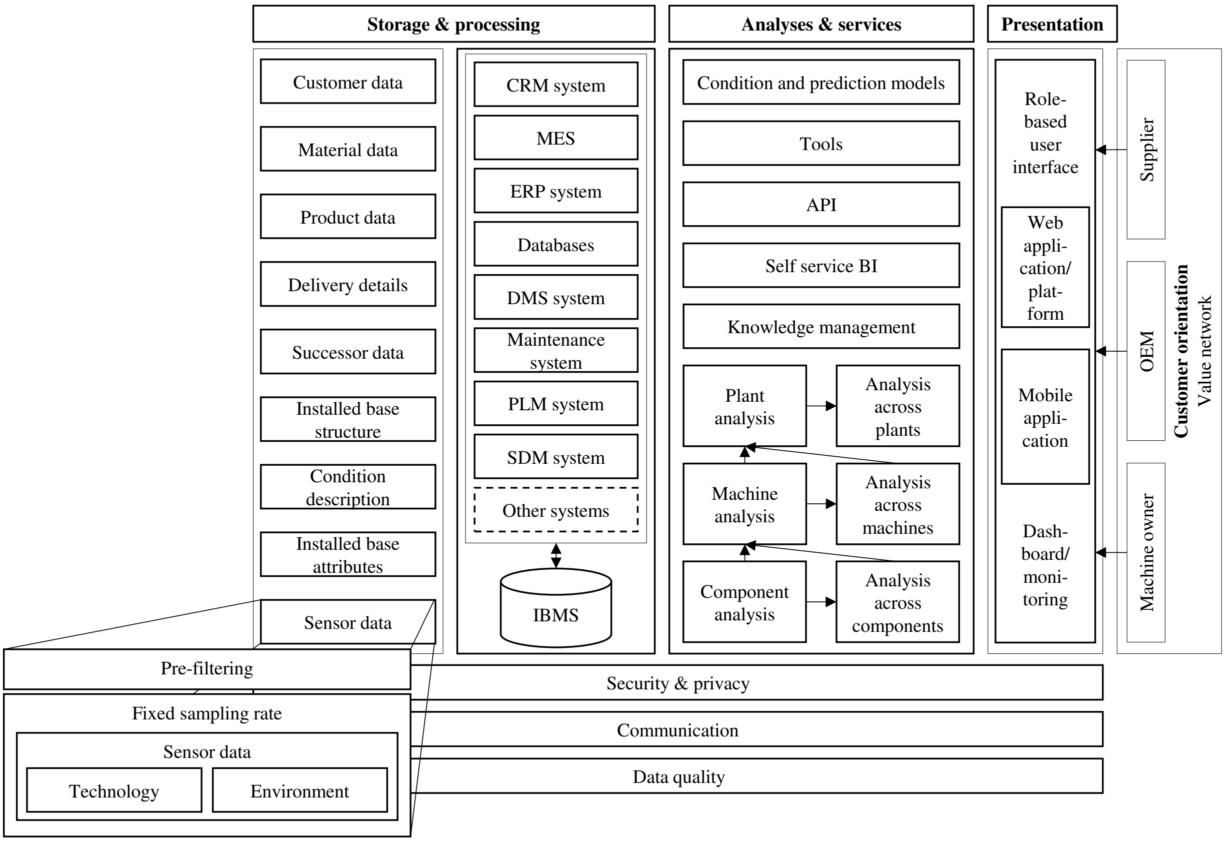

Figure 3. Integrated installed base management system

Within the mentioned applicability check, the installed base is mapped without regarding rapidly changing condition monitoring data. This is made up in the second step. Two additional cycles are carried out, especially looking at sensor data. The framework is adapted in accordance with the practitioners from the target company. Figure 3 shows the integrated IBMS that finally resulted. The information architecture is evaluated in a test run where both master data and condition data are included. Thereby, the design principles are expanded. One of the additional design principles concern the value network. Usually, not all data and information can be provided by a single company. Therefore, several companies merge and create a value network. The integrated IBMS should support the usage by different participants.

One of the most regarded types of smart services in the manufacturing industry is predictive maintenance. Therefore, the third part of the dissertation focuses on predictive maintenance. In order to get an overview about currently existing predictive maintenance business models, a taxonomy for it is derived. The idea is to define different dimensions with different characteristics. At the beginning, possible dimensions are extracted from the literature. A sample of already realized business models is taken and the dimensions are applied. With the help of the sample, characteristics are added and dimensions are consolidated, extended or deleted. In the second iteration, another sample of business models of companies is taken that are identified through different data bases, online searches and by talking with people from an industry fair. This applies to all samples. In turn, the dimensions as well as characteristics are adapted. The process ends after the fifth iteration because no further changes are needed. The final taxonomy consists of seven different dimensions where each dimension has between three and eight possible characteristics (Table 1). Thereby, for a specific business model exactly one characteristic applies for a dimension.

Table 1. Developed taxonomy for predictive maintenance business models

Dimensions	Characteristics
Key activities	Hardware development, software development, consulting, edge computer development, provision of a public cloud, hardware retailer, universal range, provision of an application platform
Value promise	All-in-one solution, condition monitoring, connectivity, automation, forecasting, data security, data storage + software development tools
Payment model	One-time sales, time basis, Project, usage basis, hybrid
Deployment channel	Physically, www, physically + www (cloud), www (cloud) + API, www (cloud), physically + www (cloud) + API
Customer segment	Manufacturing industry, energy sector, no industry focus, high-security areas, manufacturing industry + energy sector, manufacturing industry + logistics/transport industry
Clients	B2B, B2B + B2B2B, B2B + state
Information layer	Application and services, information handling, information delivering layer, object sensing and information gathering layer, multiple

Each predictive maintenance business model has seven characteristics according to the developed taxonomy. Although there are multiple possible combinations, some combinations of characteristics occurred frequently. A cluster analysis in combination with a dendrogram enabled to identify typical combinations of characteristics. This results in six archetypes. With a share of 21 %, one of the most frequent archetypes is "hardware development". Among others, business models of that archetype are characterized by one-time sales in the business-to-business (B2B) environment. They contribute to condition monitoring activities by developing appropriate hardware.

After identifying typical business models for predictive maintenance, two concrete service ideas are presented. Both concern the field of predictive maintenance and include mathematical optimization models. The first service approach optimizes maintenance planning. In the manufacturing industry, maintenance activities are often planned according to a fixed time frame or operating hours. With the help of condition monitoring, the current state of a machine can be determined at any time. Therefore, it can also be determined if maintenance activities are necessary, independent from general guidelines. This contributes to high machine availability because unnecessary maintenance activities are avoided. An optimization model embedded in a decision support system enables to find a balance between probabilities of default of the machines and costs. Maintenance activities can be planned for several periods, looking at several machines. Thereby, maintenance activities of different machines are grouped if it is reasonable to reduce setup and fixed maintenance costs.

Another service approach concerns the spare parts inventory. Spare parts mean capital commitment which is why optimizing the number of spare parts is useful. This applies especially to spare parts that can be used for several machines. It is not necessary to have one spare part of the same type for each machine. Condition monitoring data is used to determine the current condition of machine components. The necessary number of spare parts is derived from that. As in the case of the other service idea, a decision support system is developed. It includes a mathematical optimization model as well as an algorithm. It helps to find the right balance between risk of machine downtimes and provision costs of spare parts. Within a novel service approach, spare parts are not bought but a lump-sum fee is paid for the provision of a spare part. Therefore, the service customer does not need to buy

the necessary number of spare parts. This enables to adapt the number of spare parts in each period, both upwards and downwards.

Going from the general to the specific, the dissertation provides a comprehensive insight into the topic of smart services and business models enabled by the digital transformation. An overall discussion as well as implications put the findings in a broader context. Thereby, the relevance of individualized smart services and innovative business models in the manufacturing industry is emphasized. Limitations, conclusions and an outlook complement the dissertation. The investigations contribute to a better understanding of the topic both in theory and practice.

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List of Abbreviations

ADR	Action Design Research
API	Application Programming Interface
B2B	Business-to-Business
B2B2B	Business-to-Business-to-Business
B2C	Business-to-Consumer
BI	Business Intelligence
BIE	building, intervention and evaluation
BMBF	Bundesministerium für Bildung und Forschung
CASE	Clarification - Analysis - Synthesis – Evaluation
CBA	Certified-Based Authentication
CIRP	College International pour la Recherche en Productique
CRM	Customer-Relationship Management
CSS	Cascading Style Sheets
DMS	Document Management System
e.g.	exempliy gratia / for example
ERP	Enterprise Resource Planning
et al.	et alia
HTML	Hypertext Markup Language
i.e.	id est / that is to say
IBMS	Installed Base Management System
ICT	Information and Communications Technology
InnoServPro	Innovative Serviceprodukte für Individualisierte, Verfügbarkeitsorientierte Geschäftsmodelle für Investitionsgüter
IoT	Internet of Things
IPSS	Industrial Product-Service System
IS	Information Systems
ISeB	Information Systems and e-Business Management
ISO	International Organization for Standardization
ISSN	International Standard Serial Number
IT	Information Technology

ITIL	Information Technology Infrastructure Library
MES	Manufacturing Execution System
MKWI	Multikonferenz Wirtschaftsinformatik
MQTT	Message Queuing Telemetry Transport
OEM	Original Equipment Manufacturer
OPC UA	Open Platform Communications Unified Architecture
OR	Operations Research
OTP	One-Time Password
p.	page
PLM	Product Lifecycle Management
PSS	Product-Service System
PTKA	Projektträger Karlsruhe
SDM	Sensor Data Management
SySML	Systems Modeling Language
TSISQ	Tool for Semantic Indexing and Similarity Queries
VCN	Virtual Core Network
VHB	Verband der Hochschullehrer für Betriebswirtschaft e. V.
VNA	Value network analysis
VPN	Virtual Private Network
WI	Wirtschaftsinformatik
www	World Wide Web
XML	Extensible Markup Language

Overview of Publications and Task Allocation

The following overview of publications is sorted in chronological order according to the time of publication (Table 2). The review times of the articles ranged between a few weeks and nearly two years. The main reason was that the number of review rounds differed. Therefore, the times of publication of the articles are not necessarily congruent to the course of research.

In the first publication, an information architecture for installed base management is developed that enables smart services (Dreyer et al. 2017). Thereby, a practical problem from the field served as starting point for academic research. I conducted a comprehensive literature review according to Webster and Watson (2002) to extract existing literature in the field of installed base management and digital twins. Afterwards, I formulated the problem as well as the research gap. Together with my co-authors we worked out the requirements for an information architecture that depicts the whole installed base. Thereby, we included requirements that came both from theory, i.e. existing literature, and from practice by conducting focus group discussions. We also developed and subsequently refined the information architecture as a group. The design principles were mainly elaborated by me. Except parts of the introduction, I wrote the text of the article.

The following publication presents a mathematical model in which the machine spare parts inventory is optimized by considering condition monitoring data (Dreyer et al. 2018a). The optimization model forms part of an algorithm that concretely determines the optimum number of spare parts, depending on different variables. To get a first overview of existing publications, I conducted a literature review. After that, the authors together developed the mathematical model. The same applied to the algorithm in which the model is embedded. I concretized the algorithm and worked out the representation for the article. Finally, I wrote the whole text of the article.

As the title already says, the article called “Maintenance planning using condition monitoring data” presents an optimization model that supports predictive maintenance activities (Olivotti et al. 2018b). A decision support system is developed that helps to optimize maintenance intervals. The authors together developed the mathematical model as well as the algorithm in which the model is embedded. During the whole research I additionally had a consultative function.

The IWI discussion paper number 83 is the only publication that did not form part of the main chapters of the dissertation. The article presents a framework that contributes to evaluate research ideas (Passlick et al. 2018). As this elaboration can be seen as meta-research it was estimated to be not a part of the dissertation that focuses on smart services and innovative business models enabled through the digital transformation. Nevertheless, the framework helps to visualize a new research idea and its potential regarding relevant output. At the beginning of the research process I extracted literature that presents such frameworks in the context of different research disciplines. All authors worked out the initial framework and subsequently tested and evaluated it until the final version was reached. The concept for the discussion chapter was also elaborated in a group. I did advisory work during the whole research process.

Another article deals with critical success factors that should be considered when introducing a new smart service (Dreyer et al. 2018b). The success factors were extracted from the literature and discussed as well as complemented by experts from the field of smart services and digital innovation. The paper was based on the bachelor thesis by Jan Zeren who is the second author of the article. Coming from the bachelor thesis, I first updated the literature review and identified additional critical success factors. Furthermore, I consolidated similar success factors. In the bachelor thesis, four experts were interviewed to compare theoretically named success factors with practice. In the course of research of the article, I conducted eight additional interviews that led to new findings in addition to the findings of the thesis. I wrote the whole text of the article as the thesis of Jan Zeren was not written in English.

Two articles in which I formed part of the team of authors were presented at the 10th CIRP IPSS Conference on Product-Service Systems. The first one deals with the application of a framework to develop availability-oriented business models in practice (Olivotti et al. 2018a). In the course of a research project the framework that consists of five phases was tested and evaluated. I conducted a literature search to be able to describe the state of the art of availability-oriented business models and product-service systems (PSS). Afterwards, I developed the business related parts of the presented use case. I conceptualized the discussion and wrote the respective chapter.

The second article that was presented at the 10th CIRP IPSS Conference on Product-Service Systems presents a modeling framework for integrated, model-based development of PSS (Apostolov et al. 2018). I supported the literature search as well as the literature review. I carried out formatting tasks and had a consultative function during the research process.

Another article continued the research done in the paper “Towards a Smart Services Enabling Information Architecture for Installed Base Management in Manufacturing” (Dreyer et al. 2017). The developed information architecture for installed base management was extended and evaluated through an applicability check (Olivotti et al. 2019). Thereby, a digital twin of a machine was created. I conducted a comprehensive and structured literature review, including relevant articles that were published after the presentation of the former information architecture. The authors together further refined the information architecture in iterative cycles.

One of the published articles provides a comprehensive literature review for smart services (Dreyer et al. 2019b). The current state of research is presented and research gaps are identified in order to draw a comprehensive picture of smart service research in the information systems (IS) field. I carried out a structured literature search according to Webster and Watson (2002), including eight different databases. Together with my co-authors we analyzed the literature and identified 13 topics within the field of smart services that show the focus of research in the articles identified to be relevant. Afterwards, I identified different research gaps (except for the field of technologies and big data) and evaluated their potential to contribute to novel insights. Furthermore, I wrote the whole text of the article. During the review process including several rounds, mainly I adapted the article according to the reviewers’ comments.

For a book called “Digital Customer Experience” published by Susanne Robra-Bissantz and Christoph Lattemann I translated our article that was first published in the Proceedings of the Multikonferenz Wirtschaftsinformatik (MKWI) 2018 into German (Dreyer et al. 2019c). If it was not desired by the editors, the article was not updated but only translated. Therefore, only a review process that considered formal aspects took place. I adapted the translated article formally according to the comments I received from the publishers.

An article that is not yet published but under review presents a taxonomy for predictive maintenance business models (Passlick et al. 2019). Apart from giving a comprehensive overview of realized business models in that field, six archetypes are identified. They contribute to a better understanding of how predictive maintenance business models are typically designed. Within a literature review, I identified different characteristics and definitions for predictive maintenance. In the second chapter of the article, I compared the descriptions and derived a definition valid for the taxonomy development. Thereby, I wrote the respective chapter. With basis on a bachelor thesis the authors refined, extended and consolidated the taxonomy in different iterations as a group. The same applies for the clustering where I took advisory tasks.

Another article that was submitted but not published until now takes up a research gap identified during the literature review concerning smart services (Dreyer et al. 2019b). The article focuses on the role of knowledge management for successful smart services (Dreyer et al. 2019a). I started with making a literature review to identify the current state of research of knowledge management for smart services. I pre-analyzed the literature and together with my co-authors we identified nine different characteristics of a knowledge management system for smart services. I worked out these characteristics further. Together we developed a reference model that shows all possible realizations of a knowledge management system. Coming from the literature review, I developed recommendations for the design of knowledge management for smart services. Finally, I wrote the whole text of the article.

Table 2. Overview of publications

Year	Title	Authors	Outlet	WKWI[1]	VHB Jourqual 3[2]	Chapter	Appendix
2017	Towards a smart services enabling information architecture for Installed base management in manufacturing	S. Dreyer, D. Olivotti, B. Lebek, M.H. Breitner	Proceedings of the 13th International Conference on Wirtschaftsinformatik (WI 2017), St. Gallen, Switzerland, pp. 31–45.	A	C	3.1	A1
2018	Optimizing machine spare parts inventory using condition monitoring data	S. Dreyer, J. Passlick, D. Olivotti, B. Lebek, M.H. Breitner	Proceedings of the Annual International Conference of the German Operations Research Society (OR 2016), Hamburg, Germany, pp. 459–465.	-	D	4.3	A2
2018	Maintenance planning using condition monitoring data	D. Olivotti, J. Passlick, S. Dreyer, B. Lebek, M.H. Breitner	Proceedings of the Annual International Conference of the German Operations Research Society (OR 2017), Berlin, Germany, pp. 543–548.	-	D	4.2	A3
2018	Assessing research projects: a framework	J. Passlick, S. Dreyer, D. Olivotti, B. Lebek, M.H. Breitner	IWI Discussion Paper Series, Institut für Wirtschaftsinformatik, Leibniz Universität Hannover, paper 83.	-	-	-	A4
2018	Critical success factors for introducing smart services: a supplier's perspective	S. Dreyer, J. Zeren, B. Lebek, M.H. Breitner	Proceedings of the Multikonferenz Wirtschaftsinformatik 2018 (MKWI 2018), Lüneburg, Germany, pp. 410–421.	C	D	2.4	A5
2018	Realizing availability-oriented business models in the capital goods industry	D. Olivotti, S. Dreyer, P. Kölsch, C.F. Herder, M.H. Breitner, J.C. Aurich	Procedia CIRP, vol. 73, pp. 297–303.	-	-	2.2	A6
2018	Modeling framework for integrated, model-based development of product-service systems	H. Apostolov, M. Fischer, D. Olivotti, S. Dreyer, M.H. Breitner, M. Eigner	Procedia CIRP, vol. 73, pp. 9–14.	-	-	2.2	A7
2019	Creating the foundation for digital twins in the manufacturing industry: an integrated installed base management system	D. Olivotti, S. Dreyer, B. Lebek, M.H. Breitner	Information Systems and e-Business Management, vol. 17, issue 1, pp. 89–116.	B	C	3.2	A8
2019	Focusing the customer through smart services: a literature review	S. Dreyer, D. Olivotti, B. Lebek, M.H. Breitner	Electronic Markets, vol. 29, issue 1, pp. 55–78.	A	B	2.1	A9
2019	Kritische Erfolgsfaktoren für die Einführung von Smart Services: eine Anbietersicht[3]	S. Dreyer, J. Zeren, B. Lebek, M.H. Breitner	Robra-Bissantz S., Lattemann C. (eds.) Digital customer experience, pp. 25–38. Part of the Edition HMD book series (EHMD).	-	-	2.4	A10
2019	Predictive maintenance as an Internet of Things enabled business model: towards a taxonomy	J. Passlick, S. Dreyer, D. Olivotti, L. Grützner, D. Eilers, M.H. Breitner	Submitted to: Electronic Markets.	A	B	4.1	A11
2019	Knowledge management systems' design principles for smart services	S. Dreyer, D. Olivotti, M.H. Breitner	Submitted to: Business & Information Systems Engineering.	A	B	2.3	A12

[1]Wissenschaftliche Kommission für Wirtschaftsinformatik 2008 WI-Orientierungslisten

[2]Verband der Hochschullehrer für Betriebswirtschaft JOURQUAL3

[3]The article was first published in English in the Proceedings of the Multikonferenz Wirtschaftsinformatik 2018 with the title "Critical success factors for introducing smart services: a supplier's perspective".

1 Introduction

1.1 Motivation and Relevance

The digital transformation became more and more popular in the last years. It leads to a new way how companies and private users react to their environment (Jäntti and Hyvärinen 2018). Thereby, digital technologies and their fast advancement are the main drivers of the digital transformation (De Carolis et al. 2017, Rajnai and Kocsis 2018). The Internet of Things (IoT) provides the opportunity to build systems that blend sensors and actuators with each other and with the environment (Gubbi et al. 2013, Guo et al. 2017). Multiple applications are enabled (Xu et al. 2014). Coming from that, the digital transformation leads to a holistic transformation (Henriette et al. 2016) and affects quite different areas (Heavin and Power 2018, Rachinger et al. 2018). Private consumers already benefit a longer time from digital possibilities (Berman 2012). But the development in industrial sectors is not that fast (Schumacher et al. 2016). One reason might be that organizations are struggling with disruptive concepts (Schumacher et al. 2016). This does especially apply to companies that already exist for a long time. Additionally, partially there is an uncertainty about how to start the digital transformation within a company (von Leipzig et al. 2017). Nevertheless, nearly all industries already started to exploit the benefits provided by the digital transformation (Matt et al. 2015). Organizational structures, management approaches as well as processes and the offered products are affected (Heavin and Power 2018, Matt et al. 2015). Especially in the manufacturing industry, the digital transformation provides great opportunities and individual customer requirements can be satisfied (Dombrowski and Fochler 2018).

In 2011, the term "Industrie 4.0" was presented to the public for the first time, describing the fourth industrial revolution in the manufacturing industry (Oztemel and Gursev 2018). But this term does more refer to a theoretic concept that is highly complex (Issa et al. 2018). For companies, it is difficult to put it into practice (Ardolino et al. 2017). They must understand their current situation as well as their objectives regarding digital technologies and their functions (De Carolis et al. 2017, Oztemel and Gursev 2018). Specifications are necessary, e.g., in form of guidelines or application examples. Since the term arises for the first time in 2011, it indicates that the digital transformation in the manufacturing industry is a relatively recent development, providing many different opportunities for research.

Taking a business-related view on the digital transformation, the topics of smart service systems and new business models arise. The digital transformation enables the processing and use of large amount of data (Gölzner and Fritzsche 2017, Stoehr et al. 2018). This extends the number of possible business models and enables new services (Kutzner et al. 2018), mainly smart services. Broadly speaking, smart services are services that use digital technologies to satisfy individual customers' requirements (Calza et al. 2015, Stoehr et al. 2018). Smart service systems arise, enabling interaction of people, companies, technologies and information (Beverungen et al. 2017b, Spohrer et al. 2017). In addition to common service systems, smart technologies as well as rules and algorithms are used (Beverungen et al. 2017a, Spohrer et al. 2017). Smart services can be designed in multiple ways and be provided for different types of customers (Massink et al. 2010). They are flexible and can be adapted to the current environment and situation (Wünderlich et al. 2013). For many companies, smart services are an extension of the current portfolio (Allmendinger and Lombreglia 2005). In the manufacturing industry, the portfolio mostly consists of physical products. On the one hand, smart services can complement physical products that are sold (Ghobakhloo 2018), e.g., in form of intelligent maintenance services. From the customers' perspective, it has the advantage that both services and products are coming from the same provider. On the other hand, smart services can be provided standalone (Rosemann et al. 2011). This means that they are not attached to a sold product but the customers only use the smart service, e.g., for products that they already own. From the provider's perspective, smart services mean continuous revenue (Dreyer et al. 2018b). Additionally, interaction and collaboration strengthen the relationship between customer and provider (Berman 2012). Therefore, smart services are a promising approach based in the digital transformation. For academic research, smart services exemplify the opportunities through the digital transformation. Smart service research reveals opportunities and challenges that contribute to a better understanding of the topic (Wünderlich et al. 2015). Systematic insights in different topics related to smart services and their corresponding business models create a broad view on the subject (Kamp et al. 2017). Knowledge that is gained through academic research can then be used in practice. New perspectives are introduced that help to improve and refine concrete smart service approaches.

In the manufacturing industry, the opportunities through using smart services are becoming increasingly apparent. Thereby, the availability of production machines is one of the most important topics (Mert et al. 2016). A high availability ensures that production planning can be complied (Zhuang et al. 2018). Manufacturing companies are interested in using services that ensure a certain level of availability (Haider 2011). From the customers' perspective, they are financially secured if products cannot be manufactured in time. From the perspective of the service provider, detailed information about, e.g., the production processes, machines and the environment are known (Dreyer et al. 2017). Looking at the machines, it is necessary to know how the machines are constructed. Information about the manufacturing processes of the components and how the different components work together in different applications is necessary (Olivotti et al. 2019). The structures of the machines and the interplay between the machines and within a machine must be known (Dreyer et al. 2017). Otherwise, appearing problems cannot be detected quickly and suitably (Olivotti et al. 2019). Summing this up, a reliable installed base management is necessary. But not only master data about the machines is necessary, but also dynamic data (Ulaga et al. 2010, Wollschlaeger et al. 2015). Dynamic data includes, e.g., sensor data. This data enables to determine the current condition of components, machines and whole production lines. But dynamic data cannot be considered in isolation but must always be connected and analyzed with the master data; a digital twin is created (Rosen et al. 2015). Digital twins form the basis for many different smart services within the manufacturing industry (Qi and Tao 2018). Therefore, it is important to investigate how digital twins can be designed, used and adapted.

Smart services and new business models enabled by the digital transformation are a topical subject within the information systems (IS) research and practice (Kutzner et al. 2018, Morakanyane et al. 2017). In the last years, several topics are focused in existing publications (Dreyer et al. 2019b). Nevertheless, there are still many open questions and approaches that must be investigated to draw a clearer picture of smart services and corresponding business models both for theory and practice. Especially the manufacturing industry can benefit from smart services because they enable to better understand and forecast situations (Hellingrath and Cordes 2014). Smart services enable continual optimization and adaption and thereby ensure planned production processes (Georgakopoulos and Jayaraman 2016). The manifold possibilities that are given through smart services and new business models make this topic an interesting, promising and important research field.

1.2 Research Questions and Structure of the Thesis

Following the introduction, nine research questions are answered that all relate to the field of smart services and new business models enabled by the digital transformation. To get an overview of smart services and the current state of research, a comprehensive literature review is carried out. Thereby, eight different databases are considered to identify publications in the field of smart services. The objective is to provide a comprehensive overview of research activities and resulting opportunities for further research (Dreyer et al. 2019b). Therefore, this research question is investigated:

RQ 1: What is the current state of research in the field of smart services and what are approaches for future research?

Although there are already several publications dealing with aspects of smart services and corresponding business models, a systematic overview was missing. As the topic of smart services is relatively new and several aspects are nearly unexplored, a systematic overview enables a comprehensive picture of the topic (Kamp et al. 2017). It helps to identify research approaches whose investigations contribute to a better understanding of smart services in theory and practice.

After working out a systematic literature review including all types of smart services in different branches, e.g., the health sector and smart home applications, it is focused on the manufacturing industry (Apostolov et al. 2018, Olivotti et al. 2018a). As already mentioned, most of the smart services and new business model approaches in that field contribute to a high machine availability (Apostolov et al. 2018). To get a first overview, a general approach is taken and the following research question is answered:

RQ 2: How can availability-oriented business models be realized in practice?

An existing concept that was theoretically developed (Kölsch et al. 2017) forms the basis for the investigation. It consists of five phases. In each phase, another aspect of the availability-oriented business model is focused to create a holistic business model. Thus, the five phases can be seen as guidelines to develop an own business model (Kölsch et al. 2017). To answer the second research question, the concept is applied to a concrete use case (Olivotti et al. 2018a). Answering the research question contributes to a better idea of how business models for smart services are structured.

An important aspect when talking about smart services and their realization within business models is knowledge (Chu and Lin 2011, Li et al. 2015). When analyzing data, e.g., sensor data, knowledge is required. Data can only be interpreted with knowledge, e.g., in form of mathematical models and rules (Dreyer et al. 2019a). Otherwise, it cannot be known if the data is irregular to some extent. But the knowledge is not established once but is continuously maintained and extended (Ferneley et al. 2002). Therefore, a reliable knowledge management is necessary to be able to provide smart services efficiently (Al Nuaimi et al. 2015). Smart services can be designed in manifold ways and the same applies to knowledge management, leading to the following research question:

RQ 3: How can customer-centric knowledge management systems for smart services be designed?

Although there are some characteristics that are the same for all types of knowledge management systems, there are also aspects that differ. Those characteristics are identified through a systematic literature review and categorized afterwards. It results in a structured list of characteristics of knowledge management systems for smart services, a reference model that presents the diversity of knowledge management designs as well as design principles (Dreyer et al. 2019a).

The previous two research questions can be seen as preparation to design a smart service and the surrounding business model. After that, the smart service must be transited and introduced in practice (Li et al. 2015). Independent from the specific smart service, the provider must consider different factors that are developed within the research question:

RQ 4: What are critical success factors from a provider's perspective for introducing smart services that focus individual customer needs?

On the one hand, critical success factors for introducing smart services are extracted from existing publications in the IS field (Dreyer et al. 2018b). Then, the elaborated success factors are discussed with experts from the smart service field. Furthermore, experts added success factors that are not considered in the literature. The comparison of critical success factors for introducing smart services from theory and practice helps to better understand smart service implementation (Dreyer et al. 2018b).

After considering smart services and new business models as a whole, a closer look is taken on installed base management (Dreyer et al. 2017). Both master data and condition monitoring data are collected and analyzed to make predictions (Jalil et al. 2011). This data and the resulting information must be stored systematically for all relevant components, machines and production lines; a suitable information architecture is required. Therefore, the following research question is investigated:

RQ 5: What are general design principles of an information architecture for installed base management that enables smart services?

The data comes from different sources (Borchers and Karandikar 2006). Condition monitoring data is continually changing, partially in high frequencies (Gerloff and Cleophas 2017). This must be considered in the information architecture for installed base management. For smart services, companies are working together in value networks (Olivotti et al. 2018a). Different companies provide data and information, coming from different systems. This must also be reflected in the information architecture. A flexible architecture must be designed. General design principles are worked out for the design of an information architecture for installed base management that can be used to provide smart services (Dreyer et al. 2017). Coming from a theoretical elaboration, the next question is how an implementation of an installed base management can look like in practice. This is reflected in the sixth research question:

RQ 6: How can an integrated installed base management system (IBMS) be designed and implemented in practice?

A machine that is used for demonstration purposes forms the basis for the creation of a digital twin (Olivotti et al. 2019). The designed installed base management architecture is used to realize a system for handling all related data. Data that come from different sources and systems are integrated. Not only master data are considered but also sensor data that are collected in high frequencies. The application example shows how the designed information architecture can be realized in practice. Additionally, the answer of the research question closes the gap between theory and practice.

Especially predictive maintenance is named when talking about smart services in the manufacturing industry (e.g., Demoly and Kiritsis 2012, Kaiser and Gebraeel 2009). The reason is that a suitable maintenance strategy is highly important to ensure a certain level of availability (Wang et al. 2009). The way how predictive maintenance business models are designed is manifold. To get a first overview, an investigation of this research question is carried out:

RQ 7: How does a taxonomy for predictive maintenance business models look like?

The objective of this research is to identify the different types of predictive maintenance business models (Passlick et al. 2019). It is investigated in which points business models that are put into practice differ. Therefore, already realized business models of companies from different industries all over the world are considered. Through the taxonomy it is investigated how predictive maintenance business models work in practice. Companies are able to view their business model in the context of other business models. It contributes to better understand how business models for predictive maintenance look like in practice.

Maintenance schedules are an important aspect when talking about predictive maintenance. Suitable maintenance planning contributes to availability (Wang et al. 2009). Additionally, costs are saved (Bousdekis et al. 2016). Several factors influence the optimal maintenance schedule (Olivotti et al. 2018b). This is investigated in the eighth research question:

RQ 8: How can maintenance schedules be optimized using condition monitoring data?

The use of sensor data enables to consider the current condition of machines (Peng et al. 2010). It helps to determine when maintenance activities are necessary (Olivotti et al. 2018b). Mostly, there is not a single machine in the production facility but several ones. Necessary maintenance activities of the machines should be coordinated to minimize fixed costs. A decision support system that includes an optimization model determines the optimum maintenance plan for several machines over several periods. Thereby, having a sufficient number of spare parts is a necessary precondition (Dreyer et al. 2018a). This leads to the last research question:

RQ 9: How can a spare parts inventory be optimized using condition monitoring data?

For maintenance purposes spare parts are usually necessary (Elwany and Gebraeel 2008). Therefore, the number of spare parts should be sufficient at any point in time. The challenge is that different machines can use the same part type (Dreyer et al. 2018a). Therefore, it is not necessary to have a spare part for each component. Fixed capital can be reduced thereby. An optimization model forms the basis for a new service concept in which the number of spare parts can be adapted in each period (Dreyer et al. 2018a). The smart service approach shows exemplary how innovative smart services in the manufacturing industry can look like.

All research questions contribute to a better understanding of smart services, both in theory and practice. Different perspectives are taken and it is shown how smart services are embedded in business models. It starts with general approaches in the first four research questions and aims at giving an overview of smart services and business models resulting from the digital transformation. After that, it is focused on the manufacturing industry. Installed base management and digital twins are the basis that is usually used for smart services in the manufacturing industry. Therefore, the research questions RQ 5 and RQ 6 focus on this aspect. The last three research questions take a closer view on predictive maintenance. It is a class of smart services within the manufacturing industry environment that is one of the most important services when focusing on machine availability. Concrete smart services and business model approaches show how designs can look like. After answering all nine research questions, an overall discussion embeds the research results in a broader context. Different aspects are critically reflected and limitations are derived from that. Conclusions and an outlook in form of approaches for further research complement the dissertation. The following Figure 4 summarizes the structure of the dissertation.

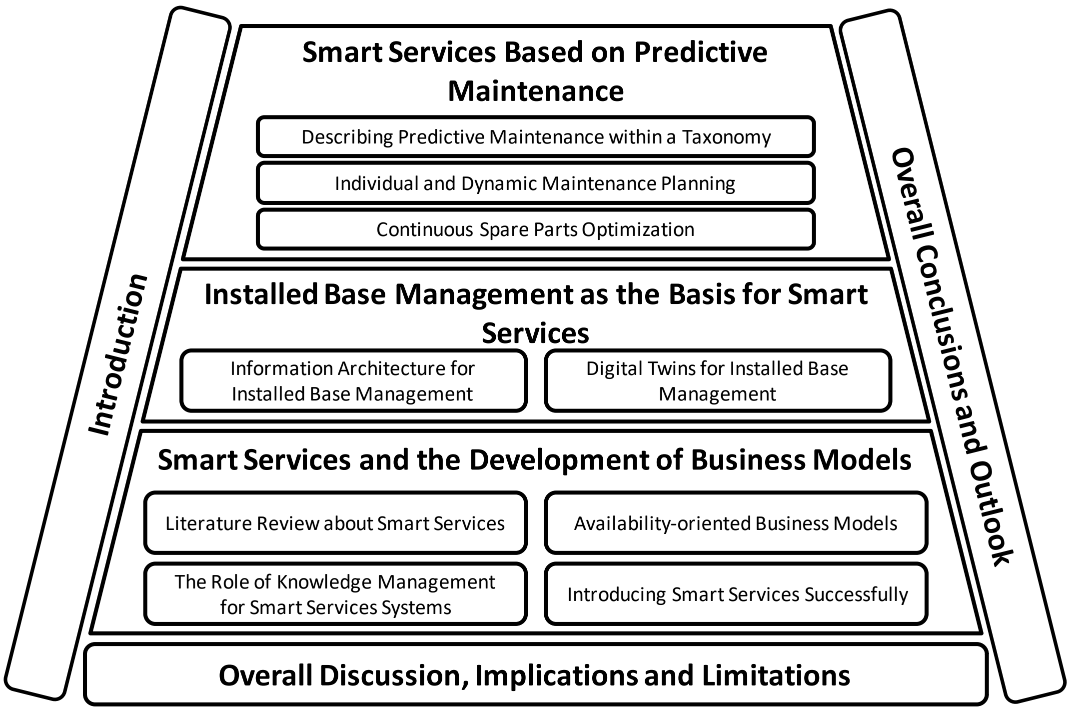

Figure 4. Structure of the dissertation

2 Smart Services and the Development of Business Models

"Smart services are individual, highly dynamic and quality-based service solutions that are convenient for the customer, realized with field intelligence and analyses of technology, environment and social context data (partially in real-time), resulting in co-creating value between the customer and the provider in all phases from the strategic development to the improvement of a smart service." (Dreyer et al. 2019b, p. 3)

In different publications the understanding of smart services is similar. Many aspects are named several times but nevertheless there was no generally accepted definition existing. Therefore, an own definition was derived. The above mentioned definition of smart services was developed based on existing literature and presented in Dreyer et al. (2019b). It includes all aspects that are determined to be necessary characteristics of smart services. As stated in the definition, what is special about smart services is that they serve the customer's specific, maybe continually changing needs (Massink et al. 2010). Therefore, smart services are always individualized, considering the used technology, the environment and social contexts (Alahmadi and Qureshi 2015, Lee et al. 2012). As the circumstances are not static but dynamic (Al Nuaimi et al. 2015), the provided smart services also have to be dynamic to be able to satisfy customer needs continually. Another aspect that must be considered to satisfy customer needs is the quality of the smart service (Yachir et al. 2009). It refers to the concept that the quality of processes is decisive for economic success (Gerke and Tamm 2009).

Smart services are a new type of services that becomes more and more present when talking about new business models (Georgakopoulos and Jayaraman 2016). The growing digital transformation and the IoT enable to involve a large volume of data for decisions in (near) real-time (Beverungen et al. 2017b). Many products are already able to record data or it is possible to add external sensors to determine the current contexts (Byun and Park 2011, Delfanti et al. 2015). Information from different sources is collected and presented afterwards, or suggestions are made using data analysis (Kynsilehto and Olsson 2012).

In the context of the digital transformation smart services are strictly based on field intelligence (Allmendinger and Lombreglia 2005). It describes that the interplay of technologies and systems leads to a higher intelligence than any of the individual parts has.

This is made possible by high dynamics and context information (Byun and Park 2011, Oh et al. 2010). A service is smart if the support from technology such as information and communications technology (ICT) is broad together with the ability to react to an individual's context and its changes (Calza et al. 2015). Therefore, apart from technology and analyses a key aspect is that value is co-created via machine intelligence and connected systems (Gavrilova and Kokoulina 2015). The term describes that interaction must take place between the smart service provider and the customer (Baldoni et al. 2010, Demirkan et al. 2015, Wünderlich et al. 2013). This interaction is important because not all information can be gathered from data. Know-how about processes, structures and systems must be provided in addition by the customer. The requirements of the customers must be communicated and feedback must be given regularly (Wünderlich et al. 2015). This enables to continually adapt and improve processes, in the business-to-business (B2B) as well as in the business-to-consumer (B2C) sector (Massink et al. 2010).

For physical products it is already established to think in terms of their lifecycle (Fischbach et al. 2013). This idea is also applied to services as there are also phases existing from the strategic development to improvement (e.g., Niemann et al. 2009, Wiesner et al. 2015). The Information Technology Infrastructure Library (ITIL) worked out a concept that contains five phases in the current version that is from 2011. Their framework is widely accepted and contains approaches that are already evaluated in practice (Cater-Steel et al. 2011). The ITIL service lifecycle is suitable for quality-based services that use information technology (IT) (Gerke and Tamm 2009). This characteristic is also true for smart services, as it can be seen in the definition. Therefore, it is referred to the named concept when talking about the smart service lifecycle in the following.

In the first phase the *smart service strategy* is developed and conditions are defined. The identification of a suitable business model also forms part of this phase. The second phase considers the *smart service design*. This phase contains all activities that prepare the provision of the smart service that is already defined from a strategic perspective. Necessary infrastructures, service platforms and further aids are designed. During the *smart service transition*, what is the third phase of the smart service lifecycle, the service is implemented. It is followed by the *smart service operation*, describing the use phase of a smart service. The last phase is the *continual smart service improvement*. It represents the learning from past successes and failures as well as the constant focus on changing customer needs. This phase is permanently existent, parallel to the other four phases that form a continuous cycle.

2.1 Literature Review about Smart Services

This chapter is based on the research article that is called "Focusing the customer through smart services: a literature review" by Dreyer et al. (2019b) (see Appendix A9). The article is published in the journal "Electronic Markets", the international journal on networked business. This academic journal focuses on electronic market issues as well as the collaboration of information technologies, commerce and social aspects. It concludes research that covers technological, organizational, societal and political perspectives. The article is published within the special issue called "Smart services: the move to customer orientation". The VHB-Jourqual 3 rates the journal with a "B". The Electronic Markets is published at Springer Berlin Heidelberg.

The literature review in the published article includes literature until the end of 2016. This chapter can be seen as an updated version. In the published version of the article 109 publications were included in the literature review. This update contains 36 further articles, all of them published in 2017 or 2018.

2.1.1 Motivation and Purpose

In recent years a growing interest about smart services has been reported in IS research (Dreyer et al. 2019b). With a rising interest in the IoT, smart services also became more and more popular in academic research (Georgakopoulos and Jayaraman 2016). When talking about that kind of services, many different aspects can be the focus. This is also reflected in the literature. But there was no systematic overview existing that shows which fields related to smart services are investigated and how intensively they are discussed. A research agenda is neither existing. From a research perspective, a systematic overview helps to better understand smart services (Kamp et al. 2017). The same applies for practitioners. The more it is known about this new kind of services the more suitable they can be provided. The following research question is therefore investigated:

RQ 1: What is the current state of research in the field of smart services and what are approaches for future research?

To show which topics in the field of smart services are investigated, this chapter aims at giving a systematic overview. A structured and comprehensive literature search following the approach presented by Webster and Watson (2002) forms the basis for subsequent analyses. The overview includes both a topic-centered and an organizational perspective. The organizational view is addressed by looking at the smart service lifecycle, from the strategy development to the continual improvement. The overview forms the basis for the identification of research gaps within smart service research. Past research and approaches for further research draw a comprehensive picture of research in the field of smart services.

2.1.2 Research Approach

In order to provide a broad literature review about smart services, a systematic literature search is conducted following the approach presented by Webster and Watson (2002). A “Tool for Semantic Indexing and Similarity Queries” (TSISQ) (Koukal et al. 2014) is used in addition to the methodology presented by Webster and Watson (2002). It uses latent-semantic indexing to identify similar texts, independent from specific search terms. For the systematic literature search, search terms are predefined. The first selected search term is “smart services”. Additionally, the search terms “digital service” and “electronic service” are chosen. The reason for the second and third search terms is that these two terms are often used as synonyms for smart services, especially in earlier publications. To summarize in short, the search terms that are used are:

- "smart service" OR "smart services"
- "digital service" OR "digital services"
- "electronic service" OR "electronic services" OR "e-service" OR "e-services"

After identifying the search terms, eight databases are selected in which the systematic literature search is conducted. These databases include ACM, AISeL, Emerald Insight, IEEEXplore, InformsOnline, JSTOR, Science Direct, and SpringerLink. The databases are chosen because they provide articles from the most important outlets that form part of different rankings in the field of IS.

The objective is to identify literature that focuses on smart services, respectively certain aspects of smart services. Therefore, we do not search for the selected search terms in whole articles but in the title and/or the abstract. For SpringerLink and InformsOnline it is not possible to restrict the search. Therefore, a full-text search is conducted in these two databases.

Inclusion and exclusion criteria are predefined to identify suitable results. Both formal criteria and content criteria are applied. A formal criterion is that only articles in English are included in the literature review. This is because most research articles are written in English, independent from the native language of the researchers. By not including articles in other languages, regional overrepresentations are avoided. Furthermore, all articles that are included in the literature review must be peer-reviewed articles. Thus, whitepapers, book chapters and further publications are filtered out to ensure a certain scientific standard. Only articles in the field of IS research are selected for the literature review because the literature review aims at giving an inside in smart service research in that field. The criterion is applied by using filters whenever possible while searching the different databases. Additionally, articles that use one of the search terms in their abstract without subsequently focusing on that topic are excluded.

The largest reduction of possibly suitable articles is reached by checking whether the authors used smart/electronic/digital service according to the definition given at the beginning of Chapter 2. Especially for articles that do not use the term smart service but electronic or digital service, it must be ensured that they used it as synonym for smart service following the given definition.

After applying all mentioned criteria, 135 articles are identified to be relevant for the literature review. All articles form the basis for both a backward and a forward search (Webster and Watson 2002). In the backward search the literature that is used in the articles is examined whether there are further relevant articles. During the forward search it is checked in which publications the 135 articles are cited. Eight further articles are identified through the explained two methods. In addition, the TSISQ is used to identify semantically similar articles (Koukal et al. 2014). Two articles are found through it.

All identified articles that contribute to smart service research in the IS research field are categorized regarding the considered phases of the smart service lifecycle. The five different phases are explained in Chapter 2. The topics that the articles cover are analyzed afterwards. Without predefining the topics, it is worked out that all articles cover at least one of in total 13 different topics.

Based on the covered smart service lifecycle phases and the topics dealt with, a heat map is created. The heat map shows how many articles are published dealing with a specific topic in the different lifecycle phases. It forms the basis for the discussion of important research fields as well as research gaps.

2.1.3 Summary of the Findings

The first article that deals with smart services was published in 2003, using the term "electronic service" (i.e. Zo 2003). From then on, the research interest in smart services grew continually. Until the end of 2016, 109 research articles consider smart services. In 2017 and 2018, 36 additional articles were published (Table 3). In the first step, it is looked at the smart service lifecycle phases that they cover. Then, the thematic foci are evaluated.

There is no article that considers the whole lifecycle of a smart service with its five phases from the development of the strategy to the continual service improvement. There are a few articles that cover three phases but that is the highest number of phases observed in a research study. Until the end of 2016, smart service design was the lifecycle phase that is covered by most of the articles. The smart service strategy and smart service transition were also explored frequently. The situation is different for smart service operation. Until the end of 2016, only five articles out of 109 deal with this lifecycle phase. Thereby, smart service operation is the least considered phase in the field of smart service research. The second fewest number of articles is found for the smart service improvement. Looking at the articles that were published in 2017 and 2018 and deal with smart services, the described tendency of considered lifecycle phases is still valid. From in total 36 identified articles, 22 consider the smart service design. Thereby, this is the lifecycle phase that is mostly considered. For example, Da et al. (2018) describe how to design a platform for smart services. Vogel and Gkouskos (2017) also look at possible platforms but with a focus on open approaches for architectures. The smart service strategy is also frequently discussed. Klein et al. (2018) examine barriers to smart services in the manufacturing industry. Another example is Anke (2019) who deals with financial aspects of smart services. In contrast to earlier publications, the interest in the smart service transition phase has declined. As before, the smart service improvement is discussed fairly rarely. The smart service operation is still the lifecycle phase that is least considered. Table 3 lists all identified articles published in 2017 or 2018 and their covered lifecycle phases.

Table 3. Publications from 2017 and 2018 categorized by covered phases of the service lifecycle

Author	Service strategy	Service design	Service transition	Service operation	Continual service improvement
Anke (2019)	•				
Badii et al. (2017)		•			
Beverungen et al. (2017b)	•		•		
Bullinger et al. (2017)	•	•			•
Da et al. (2018)		•			
Eniser et al. (2018)			•	•	
Guo et al. (2017)		•	•		
Haubeck et al. (2017)	•				
Herterich (2017)		•			
Hirt et al. (2018)					•
Hirt and Kühl (2018)		•			
Huang et al. (2017)		•			
Huang (2018)	•				
Kamp et al. (2017)	•				
Kim et al. (2017)		•			
Kim (2017)	•	•			
Klein et al. (2018)	•				
Laubis et al. (2018)		•			
Lim and Maglio (2018)	•				•
Maleki et al. (2018)	•	•	•		
Maurer and Schumacher (2018)	•				
Mittag et al. (2018)		•	•		
Nezhad and Schwartz (2017)		•			
Odefey et al. (2018)		•			
Pereira et al. (2018)				•	
Pourzolfaghar and Helfert (2017)	•	•			•
Savarino et al. (2018)		•			•
Song et al. (2017)	•				
Stoehr et al. (2018)			•		
Tang and Guo (2018)		•			•
Tsai et al. (2018)		•	•		
Vogel and Gkouskos (2017)		•			
Walderhaug et al. (2018)	•	•			
Wiegard and Breitner (2017)	•				
Wutzler et al. (2017a)		•		•	
Wutzler et al. (2017b)		•			•
Total number of articles	**15**	**22**	**7**	**3**	**7**

Apart from the considered smart service lifecycle phases, the thematic foci of the articles are also examined. From in total 13 topics, technology is by far the most considered topic. Huang et al. (2017) describe how to collect and transmit large amount of sensor data. A framework is developed that enables sensor data handling from various devices at the same time. Taking a more general view, Pereira et al. (2018) compare different middleware platforms for smart services. A trustworthy networking system is developed (Kim et al. 2017). With a focus on security aspects, a system is developed that prevents malicious attacks on smart devices used for smart services. Data is also frequently the focus of discussion. It is researched how to avoid unintended data redundancy and inconvenient links between data (Tang and Guo 2018). An environment is proposed that contributes to the objective. Odefey et al. (2018) start one step earlier, namely at the data preparation. In order to optimize processes, a workflow is proposed that defines how to prepare data from machines at different locations. After filtering and preparing data, it can be analyzed. In 2017 and 2018, four articles dealt with the topic of machine learning in the context of smart services. Machine learning can enable to make predictions across data from different sources as well as the exchange of analytical models (Hirt and Kühl 2018). Odefey et al. (2018) propose an application of machine learning where it is used to provide additional information to the customers, e.g., benchmarking data or advices on machine parameters.

When designing an architecture for smart service systems, security aspects must be considered. Guo et al. (2017) argue that a subsystem should be implemented to connect multiple devices securely. Pourzolfaghar and Helfert (2017) also define security and privacy aspects as central for smart service success. By omitting these issues, customer satisfaction is jeopardized. Related to data, knowledge is an important source for smart services. Therefore, knowledge management should be service-oriented (Haubeck et al. 2017). Maleki et al. (2018) have the opinion that knowledge management should already be considered during the design process of a smart service.

In contrast to articles published until 2016, the relative number of publications dealing with the customer involvement has increased. Bullinger et al. (2017) argue that the aspect of value co-creation must necessarily be considered when deriving new business models. It is also necessary to integrate the customer during the whole service management process (Nezhad and Schwartz 2017). Platforms and functionalities should also be applied to the specific needs of the customer. In the field of smart cities, usage behavior is used to predict the services that are used in the future (Badii et al. 2017). The user interface also plays a role. But compared to earlier publications, it is not that much in focus anymore. Only two articles concern the user interface when researching smart services.

Table 4. Publications from 2017 and 2018 and their thematic foci within the field of smart services

Author	**Technologies**	**(Big) data**	**Standardization**	**Security/privacy**	**Service quality**	**Customer involvement**	**Trends**	**User interface**	**Usage behavior**	**Business model**	**Knowledge management**	**Pricing**	**Machine learning**
Anke (2019)							•			•		•	
Badii et al. (2017)		•							•		•		
Beverungen et al. (2017b)	•		•			•	•	•		•		•	
Bullinger et al. (2017)	•					•				•			
Da et al. (2018)	•												
Eniser et al. (2018)	•	•											•
Guo et al. (2017)	•		•	•				•					
Haubeck et al. (2017)	•										•		
Herterich (2017)													
Hirt et al. (2018)	•	•	•			•							
Hirt and Kühl (2018)		•		•							•		•
Huang et al. (2017)	•	•		•									
Huang (2018)						•			•			•	
Kamp et al. (2017)	•						•			•			
Kim et al. (2017)	•			•									
Kim (2017)	•									•			
Klein et al. (2018)				•		•							
Laubis et al. (2018)	•	•											
Lim and Maglio (2018)		•		•	•		•						
Maleki et al. (2018)	•										•		
Maurer and Schumacher (2018)	•				•	•	•						
Mittag et al. (2018)		•											
Nezhad and Schwartz (2017)	•		•			•							
Odefey et al. (2018)	•	•	•	•		•							•
Pereira et al. (2018)	•		•										
Pourzolfaghar and Helfert (2017)			•	•	•	•							
Savarino et al. (2018)	•	•											
Song et al. (2017)	•			•			•						
Stoehr et al. (2018)	•					•	•			•			
Tang, Guo (2018)		•											
Tsai et al. (2018)	•					•			•				
Vogel and Gkouskos (2017)	•		•										
Walderhaug et al. (2018)	•	•	•										
Wiegard and Breitner (2017)	•	•				•			•				
Wutzler et al. (2017a)	•												
Wutzler et al. (2017b)	•												
Total number of articles	**26**	**13**	**9**	**9**	**3**	**12**	**7**	**2**	**4**	**6**	**4**	**3**	**3**

The frequency of researching standardization aspects of smart services and smart service systems remained approximately the same. Communication standards are demanded by Beverungen et al. (2017b). They see the advantage in the fact that standardization in that field enables sharing data and functionality with different devices and systems all over the world. Walderhaug et al. (2018) refer to the standardization of the modeling of smart services itself. Taking the fishery domain as an example, they argue that a reference model simplifies the decision for a technological solution. Standards can also be referred to service quality aspects (Pourzolfaghar and Helfert 2017). In the eyes of Pourzolfaghar and Helfert (2017), standardized quality factors contribute to customer satisfaction.

In earlier publications, business models for smart services and their adequate pricing was rarely discussed in the literature. Although the consideration of these aspects is still on a low level, in some articles it is discussed. Anke (2019) provides methods for the development of smart services and digital business models. Stoehr et al. (2018) develop a maturity model for the development of smart service business models. Beverungen et al. (2017b) argue that prices should be adapted individually, such as the smart service itself. Looking at smart services related to energy supply, personalized pricing models increase the customer satisfaction. Huang (2018) takes another approach and looks at price structuring for customers who use several smart services at the same time.

Seven articles concern trends in the field of smart services. It is looked at a possible “factory of the future” to identify preconditions to foster innovations (Maurer and Schumacher 2018). Song et al. (2017) look at smart service trends in China. Table 4 summarizes the publications in the field of smart services from 2017 and 2018 and their covered topics.

2.1.4 Discussion of Results and Recommendations for Further Research

In order to get an overview about the current research foci in the field of smart services, a heat map is created (Figure 5). The 145 identified articles are assigned to the fields of the heat map. A field describes a combination of topic and lifecycle phase. Each article is assigned to at least one field. The heat map demonstrates the research progress through colors.

“Technologies” is the topic that is considered most frequently. Especially in the smart service design and transition phases this topic is examined. Although many different aspects are already considered, a systematic overview is still missing. It would be an important contribution to develop a tool that serves as recommendation for the suitable technology for the respective smart service. Related to that, a discussion around advantages and disadvantages would contribute to enable decisions regarding technological questions. Until two years ago, (big) data was the most frequently considered topic after technologies. In the last two years this has changed. Security and privacy concerns are intensively discussed when researching smart services. Nevertheless, especially privacy aspects have potential for further research. Questions regarding how two ensure privacy should be investigated systematically as it contributes to higher acceptance of the customers (Suh and Han 2003).

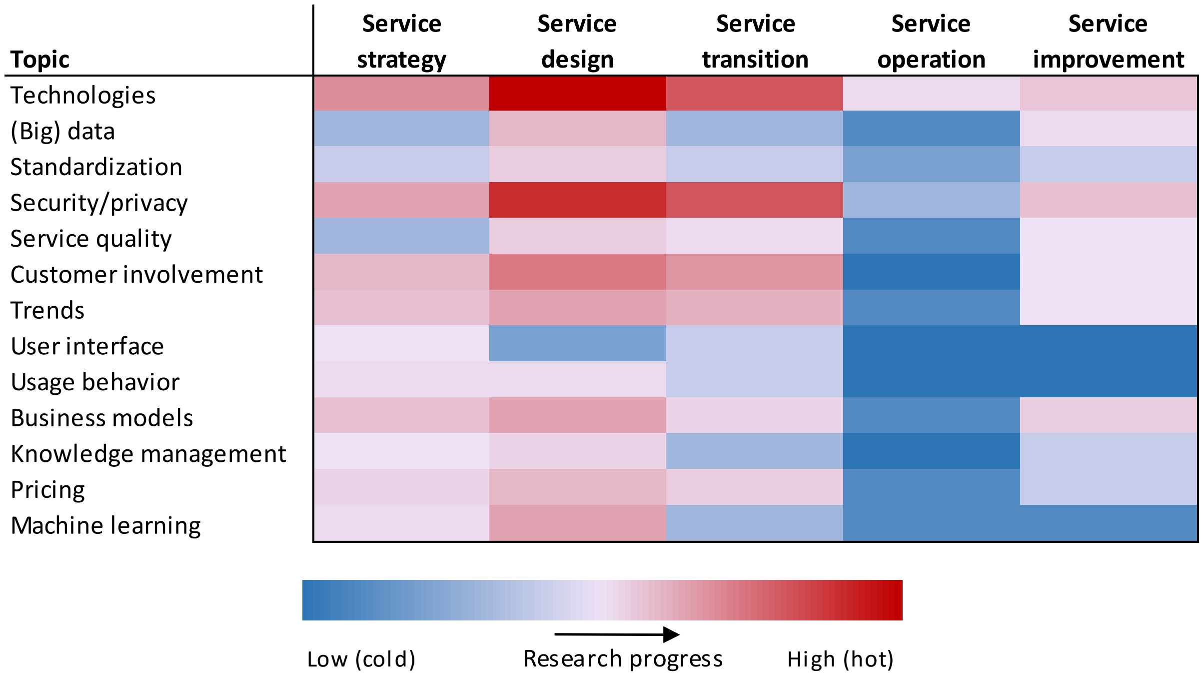

Figure 5. Heat map summarizing the research intensity

Although the number of articles that focus on the customer has increased, research is still required. The current research focuses on the customer within a specific application or a specific lifecycle phase (e.g., Spottke et al. 2016, Wang et al. 2012). An overview about the role of the customer during the whole lifetime of the smart service would lead to improved processes of those engaged in practice. Looking at the customer from an overall perspective would contribute to academic knowledge. Related to the customer, the usage behavior is a topic that is relatively unexamined. Only a few articles considered the usage behavior. Analyzing the usage behavior means to better understand the customer (Seeliger et al. 2015). As a result, the provided smart services can be optimized. Therefore, it should be investigated how the usage behavior can be reported and analyzed and what are the aspects that must be considered. The other way round, it would be an important contribution to find out how smart services can be conceptualized and designed to affect the usage behavior.

Economic aspects that are represented by the topics called “business model” and “pricing” in the heat map, are rarely examined within smart service research. For a successfully provided smart service it is necessary to elaborate a business model in the first two phases of the smart service lifecycle that is suitable for the respective smart service. It might be interesting to investigate what are the differences between established business models and business models for smart services. A smart service business model framework could be derived from that. Pricing is an important aspect when designing a smart service (Williams et al. 2008). The best pricing strategy depends on different aspects such as the type of customer, the industry and the corporate strategy. An investigation of further possible influencing factors would lead to a better understanding of suitable pricing. A decision support system could be developed that serves practitioners to identify the best pricing strategy for their smart service.

2.1.5 Limitations, Conclusions and Further Research

In 145 articles 13 topics were identified that are the foci of research in the field of smart services. Although there are many topics that are investigated in different phases of the smart service lifecycle, there is still research required. Especially topics related to economic aspects and the customer reveal potential for further research.

The created heat map that demonstrates the research intensity in the field of smart services is based on a systematic literature review according to Webster and Watson (2002). Three search terms were predefined and the search process was conducted in eight different databases. After predefining the search terms they were not extended. The eight scientific databases were determined to be the most important ones within the IS research. Nevertheless, other or additional databases might have led to other results and thereby to a different heat map. Another limitation is that only one of the three search terms contained the word “smart” to describe the service type. Therefore, for the search terms “digital service” and “electronic service” the definition presented in Chapter 2 was used to identify whether the authors of the articles are talking about smart services according to that definition. As there is no generally accepted definition existing, an own definition was derived. Therefore, another definition might have led to other literature search results.

The interest in smart service research is still growing. Many different aspects are already considered in the IS research. Nevertheless, there is much potential for further research. Closing the research gaps revealed by the heat map leads to a comprehensive understanding of smart services in theory as well as in practice.

2.2 Availability-oriented Business Models

The chapter bases on the two articles “Realizing availability-oriented business models in the capital goods industry” (Olivotti et al. 2018a, see Appendix A6) and “Modeling framework for integrated, model-based development of product-service systems” (Apostolov et al. 2018, see Appendix A7). Both were submitted and excepted for the 10th CIRP Conference on Industrial Product-Service Systems. The conference was hold from May, 29 to 31 of 2018 in Linköping (Sweden). The theme of the conference was “Resource efficient and effective solutions”. Not only researchers are addressed with the annual event but also business leaders and practitioners. All research results were welcomed that focus on product-service systems (PSS), i.e. combinations of physical products and services that simplify or enable to exploit the potential of the products. The two articles were published in the Procedia CIRP, volume 73.

The two articles were written in the course of the research project called “Innovative Serviceprodukte für individualisierte, verfügbarkeitsorientierte Geschäftsmodelle für Investitionsgüter (InnoServPro)”. InnoServPro was supported by the German Federal Ministry of Education and Research (BMBF) and managed by the Project Management Agency Karlsruhe (PTKA). The project focused on the development of availability-oriented business models. Thereby, three different perspectives were taken: economical perspective, IT/data science perspective and technological perspective.

2.2.1 Motivation and Purpose

In the manufacturing industry, the digital transformation leads to the provision of services in addition to products (Dombrowski and Fochler 2018), e.g., engines, gears or whole production machines. Thereby, PSS result. Such PSS become more and more relevant because they are an approach to differentiate from competitors (Tukker and Tischner 2006).

For example, data can be used to continually optimize products at the customer's side and to expand possibilities for application. As the services that are offered in combination with products are usually adapted to the individual circumstances of the customers and base on large amount of data, these services are smart services (Dreyer et al. 2019b). In the manufacturing environment, PSS and the related smart services are mostly concentrated on high machine availability (Mert et al. 2016). To be able to provide a service that guarantees a defined level of availability, a concept for availability-oriented business models is necessary (Mert et al. 2016). That kind of business models is not only interesting for researchers but also highly relevant in practice. Therefore, it is necessary that concepts and frameworks that are developed are useful in practice (Dreyer et al. 2018b). To ensure this, applications within use cases are a possibility. This approach is taken within the study presented in this chapter. A framework for availability-oriented business models (Kölsch et al. 2017) is validated through an industrial use case. Therefore, the following research question is investigated:

RQ 2: How can availability-oriented business models be realized in practice?

An already existing concept for the development of availability-oriented business models presented by Kölsch et al. (2017) is taken and applied within an industrial use case. The use case was developed in the research project that is shortly presented in Chapter 2.2. The concept consists of five phases. All phases are realized within this study to check whether it enables to develop an availability-oriented business model in practice. Within the fifth phase, an integrated PSS modeling framework is presented that formally did not form part of the concept.

2.2.2 Research Approach

In the research project that is described in Chapter 2.2, several workshops with employees from agricultural machinery, drive and automation industry, consultancy, component manufacturers and research institutes were carried out. It turned out that developing availability-oriented business models is a practical challenge. Workshops within the research project are used for continuous communication between practitioners and researchers, orienting on the action research paradigm (Baskerville and Wood-Harper 1998). Within this chapter, the concept for the development of availability-oriented business models that was presented by Kölsch et al. (2017) is applied to a use case. The concept is shown in Figure 6.

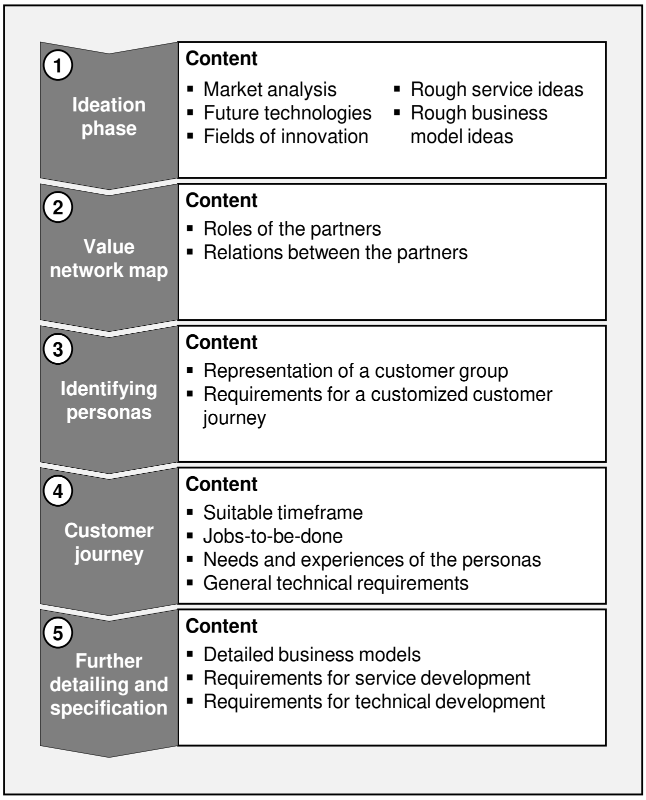

Figure 6. Concept for development of availability-oriented business models (Kölsch et al. 2017)

In total, the concept consists of five phases. All phases refer to design thinking methods in order to ensure customer-oriented development (Brown 2008). The first phase is called “ideation phase” and forms the basis for following elaborations. The market is analyzed and innovative trends, especially in the field of technology, are identified. Additionally, service ideas as well as possible business models are roughly developed. Afterwards, a prioritization takes place and the best ideas are determined. The necessary value network is worked out in the second phase called “value network map”. Necessary partners and resources are defined and their roles are clarified. The relations between the different partners are pointed out. Based on the value network, a persona analysis according to Aoyama (2005) is conducted in the phase “identifying personas”. The “customer journey” takes place in phase four (Lemon and Verhoef 2016). The requirements of the customers are identified in this phase. It aims at finding ways to support the customers. Thereby, the ideas that are worked out in the first phase are validated and additional concepts are uncovered. “Further detailing and specification” is the focus of the last phase. The business model is detailed and preconditions are worked out to be able to develop the ideas both from a technical and service perspective. In the course of the fifth phase, the general structure of an integrated PSS modeling framework is presented. It enables to specify the PSS and facilitates the design process. The framework is developed according to the "clarification – analysis – synthesis – evaluation" (CASE) research cycle (Lay et al. 2009). The idea of the framework is to create a concept for exchanging ideas for the PSS and knowledge in a network. The modeling language SysML is chosen because it supports specification, design and validation of multidisciplinary systems (Delligatti 2013, Friedenthal et al. 2014). The language is universally usable as well as extendable.

2.2.3 Realizing the Availability-oriented Business Model Framework in a Use Case

In the ideation phase several focus group discussions with participants from different companies are carried out. Search fields in three different categories, i.e. future technologies, fields of innovation and business models, are defined with the focus on availability-orientation in the manufacturing industry. A market analysis is conducted focusing services in the field of maintenance. Cloud platforms are identified as promising technologies, especially for cross-company collaboration. Such platforms provide the possibility of exchanging data, information and knowledge (Zhang et al. 2014). Additionally, data analytics turned out to be the key technology when talking about availability orientation, e.g., in form of artificial intelligence. During the focus group discussions, the fields of innovation are strongly connected to technologies. Using cloud platforms as well as data analytics while machines are running is emphasized to be highly important for availability-oriented business models.

The idea of predictive maintenance is chosen for following elaborations. A value network is necessary to be able to realize services in that field within a business model (Ehret and Wirtz 2017). The provider of the PSS takes center stage in the value network. In this use case it is assumed that the service provider is not a part of the production process of machines. Therefore, one important participant of the value network is the machine manufacturer. The manufacturer provides data and information of the machines. The component supplier also provides data, but not from whole machines but from specific components, such as motors or gears. If the service provider is not able to process and analyze this data, further participants are necessary in the value network. An external service provider might provide big data analytics. Another one might provide cloud services that enable to manage analyzed data. Furthermore, an important participant of the value network is the customer. The customer pays for guaranteed availability. The value network is summarized in Figure 7.

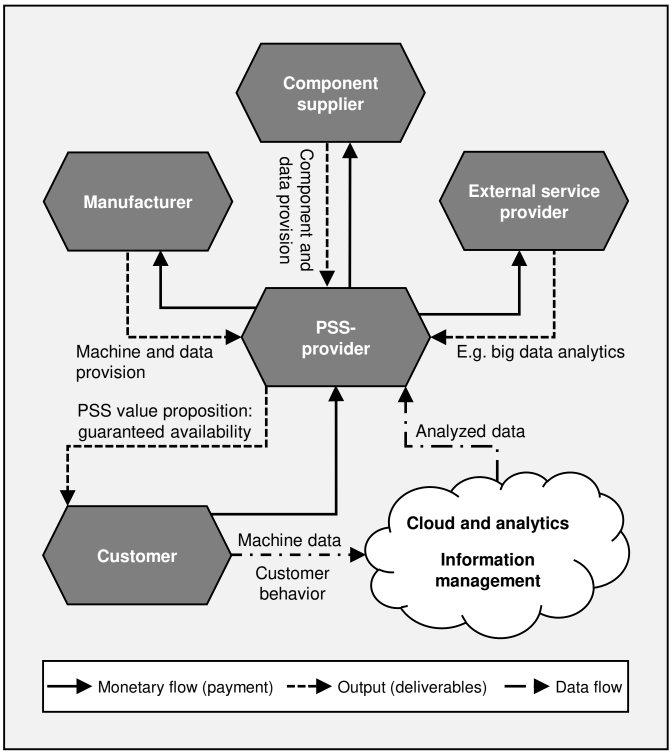

Figure 7. Value network map according to the use case

The target group is identified in the third phase. From the perspective of a component supplier, there are two possible target groups: machine manufacturers and machine users. For example, the availability of the drive unit of a machine is critical for its availability. If a component supplier provides this part of a machine, it might be interesting for machine users to take up availability-oriented services from a component supplier. The advantage for the customers is that the component supplier has extensive knowledge about one of the most important parts in the machine. But there is also the disadvantage that the service will not guarantee the availability of a machine but only of the drive unit. Therefore, services provided by machine manufacturers might be preferred. They are able to keep an eye on the machines as a whole. Nevertheless, detailed knowledge about the drive unit is missing. This forms the basis for the idea that machine manufacturers can also be the target group of a component supplier. The machine manufacturer combines its knowledge with knowledge from the component supplier who gets paid for it.

The customer journey conducted in phase four concretizes the use case and thereby the business model. A scenario is worked out in focus group discussions with participants from different companies and fields. The scenario focuses on a machine breakdown and the steps to solve it. At the beginning, it is displayed on a monitor that a failure occurred. The machine does not anymore work in its intended way. Therefore, the machine operator receives a step-by-step guideline based on experience of former errors. If it is not possible to solve the problem through the guideline, the machine operator calls for help. The maintenance staff has specific knowledge and knows past problems and activities because of a digitalized history. In combination with the maintenance staff's knowledge it is possible to save the problem. The scenario shows that a digital platform containing historical information and knowledge helps to solve errors rapidly. Nevertheless, human knowledge is also important, especially for rarely occurring errors.

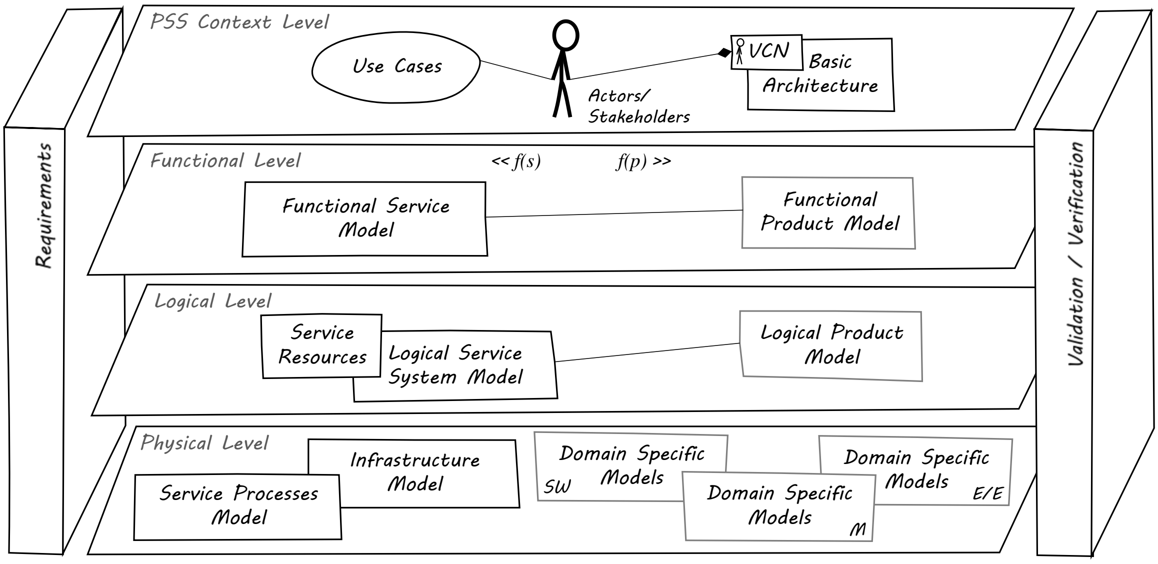

Figure 8. Concept of the integrated PSS modeling framework

For further detailing and specification of the business model, an integrated PSS modeling framework is developed (Figure 8). The framework consists of four different levels, namely context level, functional level, logical level and physical level. The levels form the solution space. Requirements are important for all levels. The same applies to validation and verification. In the PSS context level, the requirements are collected and documented. The purpose of the PSS is determined and described. The context in which the PSS should be realized is analyzed and the basic architecture is invented, considering the value network. The functional level deepens specific functionalities based on the requirements. Alternative realizations for it are discussed and verified. The necessary conditions to be able to realize the defined functions are worked out at the logical level. The requirements are concretized in specific operations. Thereby, products, IT infrastructures and necessary staff are considered. Additionally, systems outside the PSS are defined and interfaces are specified. A further concretization is carried out at the physical level. Operational procedures are detailed and resources are planned. Decisions regarding software solutions are also made and their implementation begins.

2.2.4 Discussion of Results and Implications

The presented concept can be seen as a guideline to develop business models concerning high machine availability. The five different phases presented are the basis for structured design. When designing a framework, a trade-off must be found between a general model that is applicable to different approaches and a model that is useful in practice (Lee and Baskerville 2003). From a practitioner's perspective, a useful guideline is necessary to develop a new business model. The presented use case shows how the different phases can be applied to a concrete problem in the field. The framework with its five phases guides the developer through a comprehensive development process. Thereby, it is ensured that all important aspects are considered and discussed. All steps can be applied individually. In the use case, for most of the phases focus group discussions were used to develop ideas and solutions. The discussions were combined with market analyses and further elaborations.

Especially the integrated modeling framework for PSS helps to specify the business model in the last phase. Nevertheless, it is a general concept. The advantage is that it is applicable to many different approaches. It must be considered that PSS are complex and can be developed very differently (Baines et al. 2007). An example that shows the diversity is the infrastructure to handle large amount of data. Often, a cloud server is necessary (Zhang et al. 2014) and therefore usually a cloud service provider. On the one hand, this provider must be integrated in the value network (Meier et al. 2010). On the other hand, technical aspects must be considered, such as security and privacy concepts (Wang 2011). Finding a model that considers this complexity is a challenge. Within the use case, the focus was on maintenance activities but the concept does not limit it to that. But there is the disadvantage that the phases are that general that own strategies must be developed to carry out the phases.

The model emphasizes that the value network plays an essential role. A careful selection of suitable participants is necessary for a successful business model (Mont 2002). This is especially true because knowledge is usually shared within the network (Sveiby 2001). It would be possible for a partner to leave the network and starting a business model on its own. Nevertheless, a value network is necessary to create a comprehensive picture of the production machines and their environment. Coming from that, it enables to meet the customer's changing requirements (Mert et al. 2016).

2.2.5 Limitations, Conclusions and Further Research

The research presents the practical application of a concept for the development of availability-oriented business models in the manufacturing industry. Five phases were passed in order to specify a service idea that was identified at the beginning and to build a business model around it. It aims at reducing downtimes of machines by guiding machine operators and maintenance staff. Thereby, condition monitoring data, master data and historical data were considered. Participants from different companies and different fields were involved to ensure applicability of the use case in practice. Focusing maintenance services, the phases were concretized to a specific idea. In the fifth phase, the concept for an integrated PSS modeling framework was presented that aims at specifying the business model approach. This phase especially ensured that the theoretically developed business model can be realized in practice.

The different phases are extensive and provide many aspects that must be considered and discussed. Therefore, it was not possible to present the use case as detailed as possible. For further research it should be focused on the different phases in detail in order to develop a comprehensive business model. Thereby, concepts that can be used in the different phases should be worked out to better support practitioners. Furthermore, concepts and strategies for implementation and integration should be developed.

As a single use case was considered to evaluate the usability of the framework in practice, it would also be interesting to develop further business model ideas using the guideline. In the focus group discussions, the participants already had different backgrounds. But it would be interesting to apply the concept to further companies from different sectors. Nevertheless, the framework already serves as a guideline for business model design.

2.3 The Role of Knowledge Management for Smart Services Systems

In this chapter, the article "Knowledge management systems' design principles for smart services" (Dreyer et al. 2019a) forms the basis (see Appendix A12). It was submitted to the Business & Information Systems Engineering (BISE) journal. The double-blind peer reviewed journal publishes research with a focus on effective and efficient design and utilization of IS. Different perspectives are considered that include e.g., analysis, design and implementation of IS. The potential users are not limited to a specific group and can be e.g., individuals, enterprises or the society. The submitted article was considered to be suitable for the journal because management and the use of knowledge is named as one of the focused topics of the journal. According to the VHB Jourqual 3 the journal is rated with a "B".

2.3.1 Motivation and Purpose

The examination of opportunities for further research in the field of smart services in Chapter 2.1 revealed that knowledge management in connection with smart services is nearly unexamined. But knowledge is a very important part when realizing smart services (Chu and Lin 2011, Wang et al. 2011). The requirements of customers related to smart services as well as their environment are dynamic (Oh et al. 2010). It must be reacted to changing conditions and this is enabled by knowledge. Knowledge is required to be able to turn data into information (Blair 2002), e.g., sensor data into valuable information. Summing up, a reliable and comprehensive knowledge management is required for successful smart services (Al Nuaimi et al. 2015).

Knowledge management means the handling of all types of knowledge (Fahey et al. 2001). It is based on identifying and leveraging knowledge in organizations to survive on the market (Liu et al. 2017, von Krogh 1998). Knowledge is embedded in knowledge management systems that enable to create, transfer and apply knowledge (Alavi and Leidner 2001). This is particularly the case for knowledge-intensive processes (Sarnikar and Deokar 2017). Mainly, there are three functions of knowledge management: discovering knowledge, sharing knowledge and support decision making (Fahey et al. 2001). Knowledge is dynamic and therefore complex (Alavi and Leidner 2001) what reveals challenges.

As smart services are usually realized within value networks (Abbate et al. 2015, Delfanti et al. 2015), the same applies for the corresponding knowledge management. Former knowledge management approaches refer to a single company that organizes its knowledge (Barão et al. 2017). This is changing through smart services. But within the smart service research, the role of knowledge management is usually not in focus. There is no overview existing that summarizes the characteristics of knowledge management for smart services and how they can differ. Design principles are neither elaborated for the development of knowledge management for smart services. The following research question is investigated in order to close the explained research gap:

RQ 3: How can customer-centric knowledge management systems for smart services be designed?

There is not the one best realization of knowledge management for smart services. Depending on the specific service, requirements differ (Massink et al. 2010). Within the investigation in this chapter, it is systematically examined how diverse the realizations of knowledge management systems can be when considering smart services. On the one hand, the results emphasize the importance of reliable knowledge management for smart services. On the other hand, a reference model is provided that outlines the diversity of knowledge management by presenting characteristics that differ depending on the considered smart service. Recommendations in form of design principles contribute to practical relevance.

2.3.2 Research Approach

The objective of the research is to identify requirements for knowledge management for smart services. On that basis, design principles as well as a reference model are developed. A theoretic approach is taken; publications are examined to elaborate implicitly or explicitly named requirements. As also implicitly named requirements are considered, all publications form the basis that deal with smart services. In Chapter 2.1, publications are identified that consider smart services in IS research. The literature identified there is also used for this study. The requirements for knowledge management are extracted from these publications. How the comprehensive literature search was carried out (according to Webster and Watson 2002) can be read in Chapter 2.1.

The whole texts are examined in order to identify requirements related to knowledge management. Although little attention is given to knowledge management for smart services, requirements for knowledge management are named when describing a smart service and how it is applied. Especially aspects that are specific for the described smart service are extracted. Afterwards, all aspects related to knowledge management are classified in exactly one of the three following categories: input/output, structure and reliability. These categories are not predefined but worked out during the literature review. It turns out that all aspects that are extracted can be assigned to one of these three categories. A reference model for knowledge management that represents possible types of knowledge management for smart services is developed with formal orientation on Becker and Delfmann (2007). Thereby, the three categories describe the three axes of a cube. Implications are derived that include design principles for practitioners. Figure 9 shows the explained research proceeding.

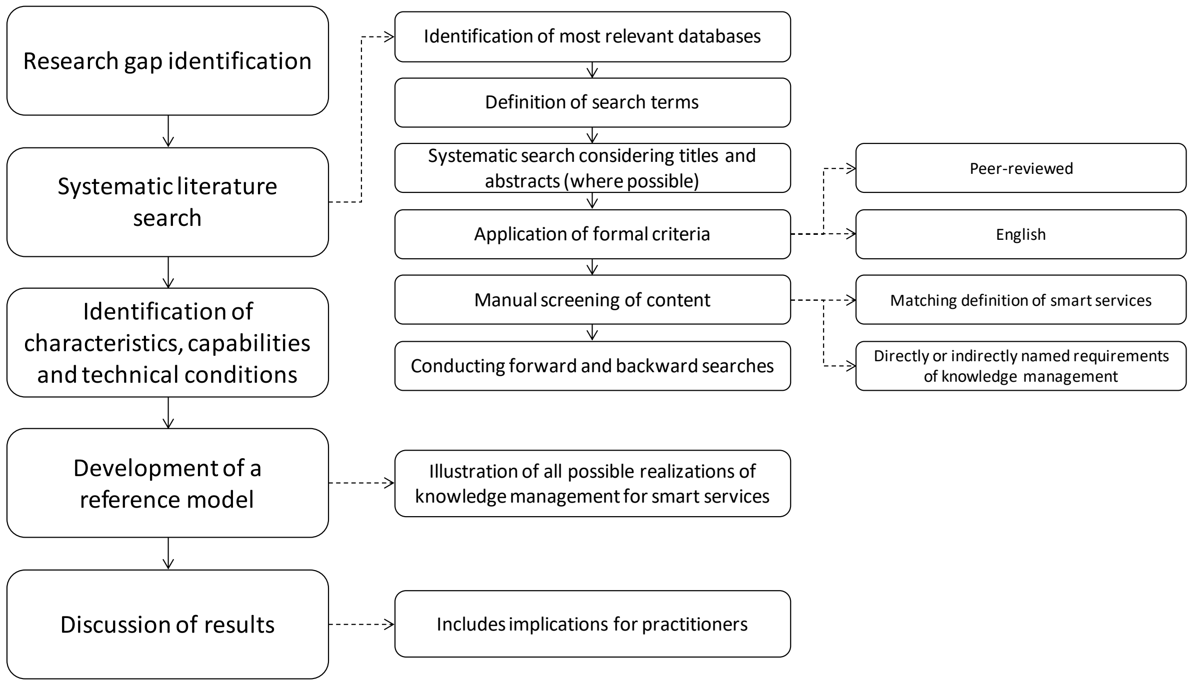

Figure 9. Research proceeding to depict knowledge management for smart services

2.3.3 Diversity of Knowledge Management of Smart Services

Considering smart services, knowledge can be seen as intellectual capital (Tianyong et al. 2006). It forms the basis for co-creating value between smart service provider and customer (Bagheri et al. 2016, Payne et al. 2008). As requirements of the customers are changing, the knowledge management system must be flexible and be adaptable to the context (Theocharis and Tsihrintzis 2013). Smart services are usually realized within value networks (Bagheri et al. 2016, Stoehr et al. 2018). Thereby, a challenge is that knowledge from different sources must be integrable (Wang et al. 2011).

Through the literature review, nine different aspects of knowledge management are identified that must be realized in different ways, depending on the smart service that is considered. They are summarized in three different dimensions of a reference model. The first dimension deals with the input and output of the knowledge management system. Input is necessary to create knowledge (Al Nuaimi et al. 2015) coming from different sources (Delfanti et al. 2015). Not only are the sources diverse but also the types of knowledge (Cellary 2013). Knowledge does not only exist in form of texts but also e.g., in form of mathematical models and algorithms (Keskin and Kennedy 2015). Additionally, there is not only direct input but also knowledge generated from operating smart services (Cellary 2013). Standardization becomes necessary to structure the knowledge (Ciortea et al. 2016). Depending on the knowledge that is required for a specific smart service, the standardization effort differs (Xie et al. 2016). But it facilitates searches as well as the processing of knowledge. Another advantage is that the knowledge is readable by different devices and tools (Ciortea et al. 2016). The form of output also highly depends on the smart service that is supported through the knowledge management system.

The second category concerns the structure of the knowledge management system. Mainly, local questions are considered in this dimension. One of the aspects is the location of knowledge storage. This is important because the knowledge management system serves not only for a single organization but for a value network (Ferretti and D'Angelo 2016). Knowledge can be either stored locally or centrally (Fan et al. 2016). It is also imaginable to use both forms at the same time. For example, general information that is relevant for all participants of the value network can be stored centrally. Specific knowledge that is only relevant for and can only be maintained by a single participant can be stored locally at the participant's side. Another argument for not storing all knowledge centrally is high sensitivity of knowledge. Depending on the smart service, an individual storage strategy must be developed. Another aspect of the structure is the location of management (Hislop et al. 2000). For some smart services it might be useful to have a central management. For smart services with very specific knowledge, several local managements might be advantageous. This aspect also depends on the storage strategy. The same applies to the location of use. When managing the knowledge centrally, it might be sensible to also use it centrally. For example, algorithms that are stored in a cloud should also be used there and not copied and used locally. An argument for that is that it ensures that the latest version of the knowledge is used. Thereby, security and performance issues must be considered.

The last of the three dimensions of the reference model is the reliability. Smart services are dynamic (Batubara 2015) and the knowledge management systems must be equally dynamic. For some smart services, very quick reactions are necessary (Holgado and Macchi 2014). This must be supported by the knowledge management system. In other cases, the speed in which a decision must be made is slower. Apart from the reaction speed, the necessary update cycles differ. This highly depends on the type of knowledge (Strüker and Kerschbaum 2012). For some cases it might be necessary to hold the knowledge as updated as possible. For other cases, a regular update cycle is sufficient. Holding all knowledge as updated as possible seems to be the best solution. But economic aspects must be considered because high update frequencies mean high costs. A balance must be found between reliability and costs. Table 5 summarizes the three described dimensions with their considered aspects.

Table 5. Aspects of the three dimensions of knowledge management for smart services

Dimension	Aspect	Description
Input/output	Diversity of sources	The more sources are considered to gain knowledge, the more complex is the knowledge management system for smart services.
Input/output	Diversity of format	Knowledge has many different formats and can be unstructured or structured.
Input/output	Standardization effort	Effort to standardize knowledge is related to the complexity of the input and output as well as the related smart services.
Structure	Storage location	Knowledge can be stored locally at a server of a value network participant or centrally, e.g., in a cloud.
Structure	Management location	Responsibility can be concentrated or distributed over the value network participants.
Structure	Location of use	Methods, models or further knowledge can be used centrally, e.g., in a cloud, or copied and stored locally for further use.
Reliability	Dynamics	The more dynamic smart services are the higher are the requirements regarding the knowledge management system's dynamics.
Reliability	Reaction speed	Smart services can make real-time reactions necessary which is why the knowledge management system often must react quickly.
Reliability	Update frequency	The higher the demands regarding reliability of the knowledge management system for smart services are the higher is the update frequency.

The three described categories form the basis for a knowledge management reference model in form of a Platonic solid. Thereby, each category represents one dimension of the resulting cube, shown in Figure 10. Each point of the cube model describes one possible realization of a knowledge management system for smart services. As a consequence, the reference model illustrates the diversity of knowledge management for smart services.

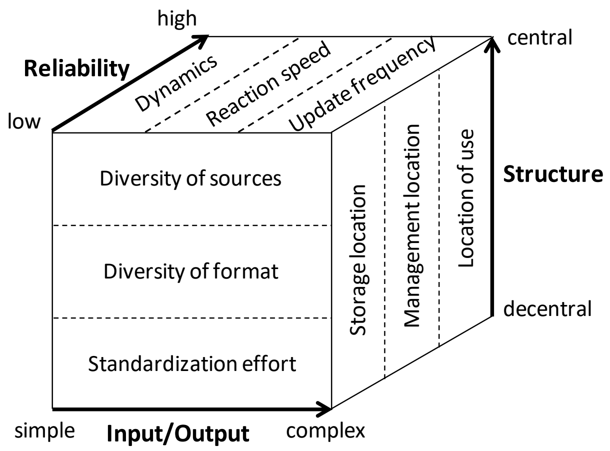

Figure 10. Cube model illustrating the diversity of knowledge management for smart services.

2.3.4 Discussion of Results

It is undisputed that knowledge management is an essential part of successful smart services (Wang et al. 2011). Knowledge enables to react dynamically to circumstances, partially in real-time, and supports decision making. Data is turned into value through knowledge (Blair 2002) combined with context information. Taking sensor data as an example, knowledge is necessary to decide whether the sensor data indicates anomalies. Knowledge is also necessary to continually adapt operating smart services (Korzun et al 2015). A knowledge management system also underlies a continual adaption (Theocharis and Tsihrintzis 2013) because e.g., new knowledge is added and redundant knowledge is consolidated. This adaption does not only happen automatically but also manually. Although the knowledge management system partially can be a learning system, manual input from experts is required. It is important that all participants of the value network form part of the knowledge management system. It ensures that expert knowledge from different areas that often only exists in the heads of the employees is implemented and held up-to-date. It is important to store this knowledge for smart service provision on the long term. Additionally, this knowledge cannot only be used by a limited number of employees but by different participants of the value network and by machines. Standardization is important to map the knowledge and its relations (Ciortea et al. 2016).

As already mentioned, smart services are provided in value networks (Dreyer et al. 2017). Therefore, the knowledge management system must also be maintained and used by the participants of the value network. These participants represent different companies as well as customers which must be considered when designing a knowledge management system. Each company has internal knowledge that must be protected. Nevertheless, this knowledge might be useful for successful provision of a smart service. Therefore, security and privacy concerns must be considered. Role-based authentication helps to ensure a certain level of security and privacy. One possible realization is that the roles differ across the participants of the value network. In another dimension it would also be useful to have different roles for different departments in the same company or even for different employees in the same department. A role concept must be developed that fits with the requirements of the value network and the smart service for which the knowledge management systems should serve. Another point that must be taken into account is that not all knowledge is relevant for all participants. A flood of data must be avoided to ensure efficiency; the output must be individually adaptable. Both processes and the technical infrastructure of the knowledge management system must be realized in a way that these requirements are fulfilled. Regarding technical conditions, the knowledge management system must be embedded adequately in existing systems and processes. Interfaces to further systems are also highly advantageous.

Apart from the controlled access to knowledge, the storage of knowledge is also an important aspect when talking about security (Jennex and Zyngier 2007). It is possible to centrally store general knowledge that is relevant for several participants. Knowledge that is specific because it is not relevant for other participants or must not become available outside the company can be stored locally. This means that it must not be decided whether all knowledge should be stored centrally or locally but there are also solutions between these two extremes. The administration of the knowledge management system must be adjusted correspondingly. Table 6 presents design principles that arise from the findings and their discussion.

Knowledge management is not only an operational issue but also relevant in the management and strategic levels. The knowledge management system and the corresponding smart service must suit to the companies’ strategies and always be oriented on the customers at the same time.

Table 6. Design principles for development of knowledge management systems for smart services

Recommendation	Comment on the application
Automated knowledge generation	The knowledge management system for smart services must be a living IS. New knowledge from operating smart services should be integrated automatically and information should be combined to generate knowledge.
Machine readability	Knowledge must be understandable both by people and machines what requires standardization.
Context sensitivity	Smart services are context sensitive as individual requirements are satisfied: the knowledge management system must contribute to that.
Use context information	Specific context information should be abstracted for knowledge management support.
Real-time reaction	For smart services, reaction in real-time is partially necessary: a knowledge management system for smart services must enable and support that.
Individual output	Depending on the smart service, context and requirements help to adapt output individually.
Value network	Knowledge is not only used across departments but also across participants of a value network.
Interfaces	The knowledge management system for smart services should be connectable to other IS and tools.
Integrability	The knowledge management system for smart services should be embedded adequately in existing IS and processes.
Security and privacy	Measures such as role-based authentication address security and privacy concerns; concepts and strategies for remote access are inevitable.

2.3.5 Limitations, Conclusions and Further Research

Knowledge management is essential for smart services (Oh et al. 2010). Therefore, in this study it was carried out which aspects must be considered when designing a knowledge management system for smart services. A systematic literature review revealed requirements that were consolidated. It resulted in a reference model. Knowledge management systems for smart services differ from other systems as they must be conceptualized for a whole value network. Participants from different companies that might be distributed all over the world use the same knowledge management system in order to provide successful smart services. The partially necessary reaction in real-time (Huang 2018, Mukudu et al. 2016) is another requirement which is why such systems differ.

Smart services are a relatively new research field (Dreyer et al. 2019b) and therefore, this also applies to knowledge management for smart services. The study bases on existing publications in the field of smart services. This is why the research results present the current understanding of knowledge management for smart services. Nine aspects were presented and consolidated in three different categories. It cannot be excluded that there are further aspects named in articles that will be published in the future. Therefore, further studies should be carried out in the future to investigate the role of knowledge management for smart services and how it changes over time. Additionally, other foci on knowledge management would be interesting. Within this study, it is focused on the design of knowledge management, mainly on a strategic level. But technical realizations would also reveal important results that contribute to a better understanding of the topic. The continual optimization of the knowledge management system is another approach that might lead to interesting results.

A theoretical approach was taken to investigate the role of knowledge management for smart services. Publications formed the basis for the elaboration of relevant aspects and the subsequent development of the reference model and the design principles. For further research, it would be interesting to match theoretical results with opinions of experts. Smart services are not theoretical constructions but highly relevant in practice. Therefore, a continuation that includes results of expert interviews or focus group discussions would emphasize practical relevance of the study. Nevertheless, the presented study provides a first systematic insight in the topic of knowledge management for smart services.

2.4 Introducing Smart Services Successfully

The following Chapter 2.4 is based on the article “Critical success factors for introducing smart services: a supplier’s perspective” by Dreyer et al. (2018b) (see Appendix A5). The paper was presented at the “Multikonferenz Wirtschaftsinformatik 2018” (MKWI 2018). The conference took place in March, 06 to 09 2018, in Lüneburg, Germany. The theme was “Data driven X — turning data into value”. The MKWI takes place every two years in the German-speaking countries. Within the VHB-Jourqual 3, the conference is rated with a “D”.

The article that was originally published in English also appeared as a book chapter in German translation with the title “Kritische Erfolgsfaktoren für die Einführung von Smart Services: Eine Anbietersicht” (Dreyer et al. 2019c) in the book called “Digital Customer Experience - Mit digitalen Diensten Kunden gewinnen und halten” (see Appendix A10). The book presents current research in the field of digital customer experience, user experience concepts as well as related topics and approaches. The book is part of the series Edition HMD that is published at Springer. The editors are Susanne Robra-Bissantz and Christoph Lattemann.

2.4.1 Motivation and Purpose

Many of the companies that want to offer or already offer smart services still exist for a longer time, mainly with focus on selling products (Geng et al. 2010). Smart services are an additional opportunity to win new customers and strengthen the relationship to existing ones (Rabetino et al. 2017). New business models are enabled thereby. Additionally, the provision of individualized smart services is a differentiating factor from competitors (Dreyer et al. 2017). Looking at the customer from a provider's perspective, such services contribute to a long-term relationship and mean continuous revenue. It can be inferred that the introduction of new smart services is an important step to gain the named advantages.

From an academic perspective, the interest in smart services is growing (Dreyer et al. 2019b). More and more literature deals with different aspects of smart services, as already presented. As mentioned before, it is undisputed that the customer plays an important role when talking about smart services (Dreyer et al. 2019b). The customer must be integrated to provide a successful smart service. Customer's requirements must be fulfilled to create a smart service that is relevant (Demirkan et al. 2015). But several preconditions must be fulfilled to satisfy the requirements. When introducing a new smart service, many different aspects must be considered. In order to help those who are introducing smart services in practice, guidelines are helpful. From a research perspective it is also interesting to investigate the factors that are decisive for the success of a smart service introduction. Therefore, critical success factors are extracted. Both theoretical investigations and practical experiences are considered. Therefore, within this chapter the following research question is investigated:

RQ 4: What are critical success factors from a provider's perspective for introducing smart services that focus individual customer needs?

2.4.2 Research Approach

The research proceeding to identify critical success factors for introducing smart services from a provider's perspective is divided into two parts. The two parts consist of a structured literature review and semi-structured interviews.

In the first part, success factors are extracted from academic literature. Using the approach from Webster and Watson (2002) relevant articles are identified that deal with the introduction of smart services. Six different databases are considered, including AISeL, IEEEXplore, JSTOR, ScienceDirect, SpringerLink, and Taylor&Francis. Search terms are predefined and applied in all six databases. It is always searched for the defined terms in the full article and not only in the abstract. In the case of IEEEXplore it is not possible to select this option. Therefore, it is searched in the metadata. The search terms are:

- introduction AND ("smart service" OR "smart services")
- introducing AND ("smart service" OR "smart services")
- advent AND ("smart service" OR "smart services")
- (initialisation OR initialization) AND ("smart service" OR "smart services")
- implementation AND ("smart service" OR "smart services")

As not all search results are suitable to identify critical success factors for introducing smart services, formal and content-related filter criteria are applied. The formal filter criteria are the same as in the Chapter 2.1. Looking at the content, it was ensured that the articles really focus on smart service implementation and that they not only name it without discussing it further. This leads to 16 articles included in the review. Both a forward and a backward search are conducted (The approach is explained in more detail in Chapter 2.1.). It resulted in two further relevant articles.

The 18 articles that are identified are screened afterwards (14 articles were identified during the published study on which the chapter is based. Four additional articles are identified by conducting the literature search for articles that are published in 2017 or 2018). Critical success factors for introducing smart services are extracted that view on smart services from a provider’s perspective. In this context, critical success factors are factors that are of particular importance for a successful smart service introduction and consequently, to remain competitive (Massink et al. 2010). After reviewing each identified article, ten critical success factors are identified.

The theoretically elaborated critical success factors form the basis for semi-structured interviews. In the interviews, twelve experts that deal with smart services from eight different companies are interrogated. The ten success factors that are identified from the literature are critically discussed. Thereby, the importance of the different success factors in practice form an essential part. Afterwards, the interviewees are asked for additional success factors. That leads to five additional critical success factors for introducing smart services that are not yet made a subject of discussion in academic literature. The following Figure 11 summarizes the research design.

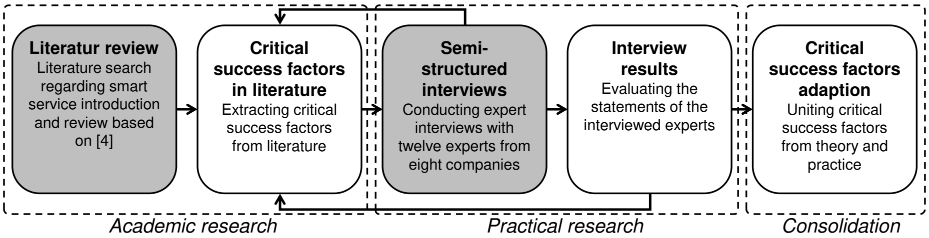

Figure 11. Research design to identify critical success factors for introducing smart services

2.4.3 Critical Success Factors for Introducing Smart Services

Critical success factors for introducing smart services successfully are both extracted from the literature and expert interviews. For the published study, 14 articles were used to identify success factors. The literature search is updated and includes now articles that were published until the end of 2018. Table 7 presents four additional articles and the named success factors.

Table 7. Relevant literature from 2017 to 2018 categorized by named critical success factors

Author	Security and privacy	Legal basis	Employee qualification	Interdisciplinary teams	Management involvement	Consideration of customer needs	Consideration of product lifecycle	IT infrastructure	Reference model use	Brand image
Beverungen et al. (2017b)							•	•		
Kamp et al. (2017)								•		
Mittag et al. (2018)	•					•		•		
Töytäri et al. (2017)					•	•		•		•

Smart services always base on a huge amount of data that is continually collected, processed and analyzed (Dreyer et al. 2019b). Therefore, cyber security and privacy are important factors when introducing smart services (Priller et al. 2014). Security and privacy concerns are of particular importance when talking about remote control (Mittag et al. 2018). Security and privacy concepts should be designed before offering smart services (Demirkan et al.

2015). Transparency regarding usage permissions and ownership of data must be considered early when a smart service is designed (Theorin et al. 2017, West and Gaiardelli 2016). Legal aspects of technical developments must also be clear (Barile and Polese 2010).

The employees of the company that wants to provide smart services should be qualified for this new field. Appropriate knowledge and skills are necessary for introducing smart services successfully (Klötzer and Pflaum 2017). Sales training is highlighted as a necessary competency (West and Gaiardelli 2016). Not only is the interaction with the customer named as a success factor in the literature but also the interaction between departments and with other partners. The interplay of different competences and experiences plays a role (Bullinger et al. 2015). The relationship with the management is also important (Allmendinger and Lombreglia 2005). The management is responsible for an innovation culture that should be reflected in the corporate strategy (Barile and Polese 2010).

The communication between the customer and the smart service provider via different channels is important (Mittag et al. 2018). It is thereby possible to identify the current customer requirements. Mittag et al. (2018) highlight that the involvement of the customer is a key aspect for the provision of smart services. Additional customer value has to be created with a smart service (Klötzer and Pflaum 2017). When interacting with the customers, their needs can be identified and subsequently satisfied. Additionally, the lifecycle of a smart service in a specific application can better be understood (Geum et al. 2016). According to Blinn (2011), knowing the lifecycle increases the value creation potential. It supports the identification of what type of smart service is relevant for potential customers.

An adequate infrastructure is necessary for e.g., remote data transfer, automated data evaluation and predictive services (Töytäry et al. 2017). Kamp et al. (2017) name the exchange of data as a key factor for smart services. Therefore, a suitable IT infrastructure including modern hardware is inevitable when providing smart services successfully (Baars and Ereth 2016). It is emphasized that an untrustworthy infrastructure is one of the reasons why smart services are not provided (Töytäry et al. 2017). A reference model can help when introducing smart services (Bullinger et al. 2015).

The brand image, also known as reputation, is a success factor that was not part of the list in the publication that was presented at the MKWI. Töytäri et al. (2017) are the only authors that consider the brand image as critical factor for introducing smart services. Experts neither named the brand image as a critical success factor. Often, companies want to offer smart services that sold products so far. Therefore, the brand image is linked with the product (Töytäri et al. 2017). But for successful smart services it is important that the brand is also linked with service aspects.

Table 8. Identified critical success factors for introducing smart services

Critical success factors	**Description**
Security and privacy	Data that is used for smart services is sensitive. An effective security and privacy concept is inevitable.
Legal basis	Transparency is necessary regarding the ownership and usage permissions of data and information.
Employee qualification	It is important to sensitize for the topic of smart services. Trainings help to understand customer needs and to improve smart service introduction.
Interdisciplinary teams	Smart services are highly complex what requires interdisciplinary teams, both internally and between provider and customer.
Management involvement	An innovation culture can only be created when the management exemplifies it. The importance of the management depends on the company structure.
Consideration of customer needs	Smart services always have to be developed for the customer. Only services that satisfy customer needs can be successful.
Consideration of product lifecycle	The lifecycle of smart services is partially different to those of products. This should be taken into account.
IT infrastructure	An appropriate IT infrastructure is a precondition for smart services because data has to be collected, transmitted, processed and analyzed.
Reference model use	Reference models that are suitable to the setting of a company are useful as orientation.
Brand image	The reputation decides how a company is perceived. The brand image should contribute to a positive impression as a smart service provider.
Project management	A flexible project management enables a quick adaption to the changing environment and contributes to implement smart services in an existing strategy.
Consideration of internal requirements	Requirements of internal stakeholders are useful as milestones and should be considered to avoid internal inconsistencies.
Business model	New smart services have to be embedded in business models. A suitable pricing strategy has to be worked out as well as suitable cooperation partners.
Consideration of the market	Cultural aspects have to be considered when introducing a worldwide applicable smart service. The market positioning is important.
Standardization	Smart services should be standardized to be able to adapt them easily and to avoid complications with partners and customers.

In addition to the critical success factors that are named in the literature, there are several factors that are named by experts. In addition to the involvement of the management, the project management is also considered to be important for the realization. It should be flexible to be able to react to changes. Thereby, not only the requirements of the customers should be considered but also internal requirements from stakeholders. The corporate strategy must be taken into account. This also applies for the design of the business model that should be pursued. Especially a suitable pricing strategy is named as a success factor within the business model aspect.

Several experts that work in the field of smart services name the market orientation as an important success factor. As companies often operate worldwide, cultural aspects must be considered. For example, the openness towards innovations influences the best marketing strategy and thereby, how to access a new market. Standardization contributes to a globally acting service. The introduction process is less complicated regarding e.g., technology. The factor of market consideration is proofed by the experts to be the most important critical success factor that is not named in the literature. Table 8 provides a summary of all success factors that are identified. Thereby, the first ten factors that are named are extracted from the literature; the latter five came from experts that deal with smart services in their daily business.

2.4.4 Discussion of Results

The elaborated critical success factors for introducing smart services show that there are many different aspects that are of importance. Additionally, the list shows that the success factors that are named in the literature do not necessarily correspond to the factors that are named by practitioners. Mainly, the experts agree with the theoretically extracted aspects. One exception is the consideration of reference models when introducing smart services. In the literature, it is recommended to use a suitable reference model (Bullinger et al. 2015). It is argued that the introduction of a new smart service requires comprehensive planning (Demirkan et al. 2015). Thereby, an abstract model is helpful. Mainly, the experts do not consider reference models to be a success factor when introducing smart services. One expert argues that it highly depends on the model. The settings of the companies are very different. It is only useful to consider a reference model that is suitable for the specific environment. Very high-level reference models do not offer value from the point of view of the experts.

In the initial study, nine different success factors were found in the literature. After updating the literature and subsequently adding four further articles, a tenth critical success factor was added. The aspect of the brand image was neither named before in the literature nor by the interviewed experts. For a company, it is important to know how the brand is associated. Regarding the provision of services, a brand must also be positively associated with that to be able to introduce smart services successfully (Töytäri et al. 2017). The reputation of a company is an aspect on which it was not looked before.

In addition to theoretically extracted critical success factors, the experts named five additional aspects. The factor of market consideration is proofed by the experts to be the most important critical success factor that is not named in the literature. It is argued that the digital transformation enables a worldwide provision of a smart service. But the markets are not the same all over the world. For example, the European market requires other strategies than the Asian market. The cultures play a decisive role when elaborating the best strategy to enter a market with a new smart service. Not only the marketing strategy should be adapted but also the way the smart service provider interacts with potential customers. Additionally, legal aspects and further issues must be considered.

All experts agreed that critical success factors are useful for introducing smart services successfully. The factors help to facilitate the orientation when entering a new field, i.e. service-oriented business models.

2.4.5 Limitations, Conclusions and Further Research

Critical success factors for introducing smart services were worked out both from theory and practice. The objective was to create a list of factors that can be used as a guideline when introducing a new smart service. For the theoretic part, a structured literature search was conducted, resulting in 18 identified articles. After that, identified critical success factors were discussed with twelve experts coming from eight different companies, all from the smart service field. Additionally, further success factors were named. At the end, a list of 15 critical success factors resulted. Thereby, the consideration of the market is estimated to be highly important by the experts when introducing a smart service for the first time. This critical success factor was not named in the literature. A success factor related to the market which was named in the literature was the brand image and reputation of the company. Nevertheless, the market consideration is an aspect only named from a practical view but not from a research perspective.

Regarding the structured literature search, there is the limitation that all search terms that were used included “smart service”. Therefore, only articles were considered that explicitly used the term “smart service”. As described in Chapter 2.1, the terms “digital service” and “electronic service” are partially used as synonyms. Furthermore, only English articles were considered for the literature review. Therefore, a literature search that includes the named terms and that also considers search results in other languages might lead to further results. The same applies to the interviews. Further interviews with other experts from other companies might also result in new knowledge regarding the introduction of smart services. Especially interviews with practitioners from branches that were not considered until now might result in new insights.

It is likely that the number of publications that deal with the introduction of smart services will rise. In practice, smart services will become more and more accepted and realized, resulting in new knowledge regarding their introduction. Therefore, the provided list of critical success factors might become longer or even change in the future compared to the presented status quo.

3 Installed Base Management as Basis for Smart Services

Installed base management forms the basis for digital twins (Rosen et al. 2015). In addition to asset management, installed base management goes deeper into the components of a machine, aiming at including every part of a machine, no matter how small or large. Installed base management enables to structure and manage machine data (Olivotti et al. 2019). The following introduction into installed base management is based on the description presented in Dreyer et al. (2017). When information from installed base management is combined with sensor data, a digital twin of a component or machine results (Alam and El Saddik 2017, Gabor et al. 2016, Rosen et al. 2015). The introduction into digital twins is based on Olivotti et al. (2019).

The objective of asset management is to support and to optimize the lifecycle of physical assets (Lin et al. 2006). This is realized by representing the different components and the machine digitally as a whole. Installed base management extents this idea and also displays the components of the components and so on. Additionally, within installed base management the interplay between these components is considered. It is realized by considering data and information from different sources such as enterprise resource planning (ERP) systems or production databases (Borchers and Karandikar 2006). Non-digitalized information also plays a role, e.g., knowledge of technicians of the machines (Turunen and Toivonen 2011). As it is in the case of all smart services, data quality is also important when talking about installed base management (Sarfi et al. 2012).

By adding condition-based data such as sensor data, a digital twin of the installed base is created (Alam and El Saddik 2017, Gabor et al. 2016, Rosen et al. 2015). Digital twins are used as a tool to be able to fulfill the high demands on availability and productivity that are present in the manufacturing industry (Haider 2011, Mert et al. 2016). A big challenge is that a production machine usually is not completely built up by a single company that has all relevant information about the components and the machine itself. Finished components are purchased from different component suppliers. Additionally, the machine builder, who potentially wants to offer the provision of a digital twin, has no information regarding the use and the current state of the machine at the customer's location (Mert et al. 2016). But the collection and analysis of condition monitoring data, e.g., sensor data, is absolutely essential (Fellmann et al. 2011, Lin et al. 2006). In turn, the customer who uses the machine lacks knowledge about detailed technical data and the interplay of the different components in a machine. Therefore, services are necessary who bring the data, information and knowledge from different sources together to form digital twins. Thus, a digital twin can be seen as a dynamic smart product (Abramovici et al. 2016). Digital twins are realistic models that represent machines including all their components, their current condition and their interplay among each other and with the environment (Gabor et al. 2016, Rosen et al. 2015). It enables the provision of different smart services (Gabor et al. 2016).

3.1 Information Architecture for Installed Base Management

This chapter is based on the article "Towards a smart services enabling information architecture for installed base management in manufacturing" by Dreyer et al. (2017) (see Appendix A1). The research results were presented at the 13th International Conference on Wirtschaftsinformatik. The conference was hold from February, 12 to 15 of 2017, in St. Gallen, Switzerland. The motto of the conference was "Towards thought leadership in digital transformation". The track in which the article was presented called "Digitalization in the industry". Among other things, it focused on business models, smart services and underlying technologies in the context of digitalization. In particular, the manufacturing industry was considered as example for the digital transformation. The article was subsequently published in the proceedings. Looking at the VHB-Jourqual 3, the conference is rated with a "C".

3.1.1 Motivation and Purpose

In the manufacturing industry, there are high demands on machine availability and productivity (Haider 2011, Mert et al. 2016). Both machines and production processes are more and more optimized. To be able to carry out optimizations, a clear picture of the machines is necessary, i.e. a digital twin (Olivotti et al. 2019). Such a digital twin in useful as basis for smart services.

A digital twin means bringing together data and information from many different sources (Qi and Tao 2018). Additionally, the digital twin is not static but dynamic because constantly changing data, i.e. condition monitoring data, is also included. Production machines are complex and value networks with, e.g., component suppliers, machine manufacturers and machines users, are necessary for realization (Zott et al. 2011). As different participants form part of the value network, knowledge is also distributed. But to be able to fulfill customer's demands regarding machine availability, knowledge from all participants is necessary (Dreyer et al. 2019a). A platform is required where all data, information and further knowledge are brought together. Condition monitoring data, often in form of sensor data, and installed base data form the basis for smart services (Fellmann et al. 2011, Lin et al. 2006). This is often reflected in the literature. Nevertheless, there is no generalized information architecture existing in the field of installed base management. Design principles help to structure an information architecture. Therefore, the following research question resulted:

RQ 5: What are general design principles of an information architecture for installed base management that enables smart services?

A generalized information architecture ensures that data and information from many different sources can be processed. For example, this means that data has to be standardized. Additionally, data and information management is necessary. Therefore, the information architecture enables that different participants can work together. It enables many different smart services in the manufacturing industry that can be provided.

3.1.2 Research Approach

Designing an information architecture and developing design principles intended for installed base management has high practical relevance. Therefore, Action Design Research (ADR) according to Sein et al. (2011) is chosen as the underlying research design. ADR combines organizational relevance and methodological rigor, a topic that is discussed within IS research (Iivari 2007, Lindgren et al. 2004). Two main challenges are addressed through ADR (Sein et al. 2011). First, an organizational problem is solved through continuous interaction between researchers and practitioners. This reflects that the starting point of the research has organizational relevance. Second, general design principles are derived from the process, addressing a broader class of problems. Through the formalization of learning, methodological rigor is ensured. Figure 12 shows the research proceeding and its five cycles.

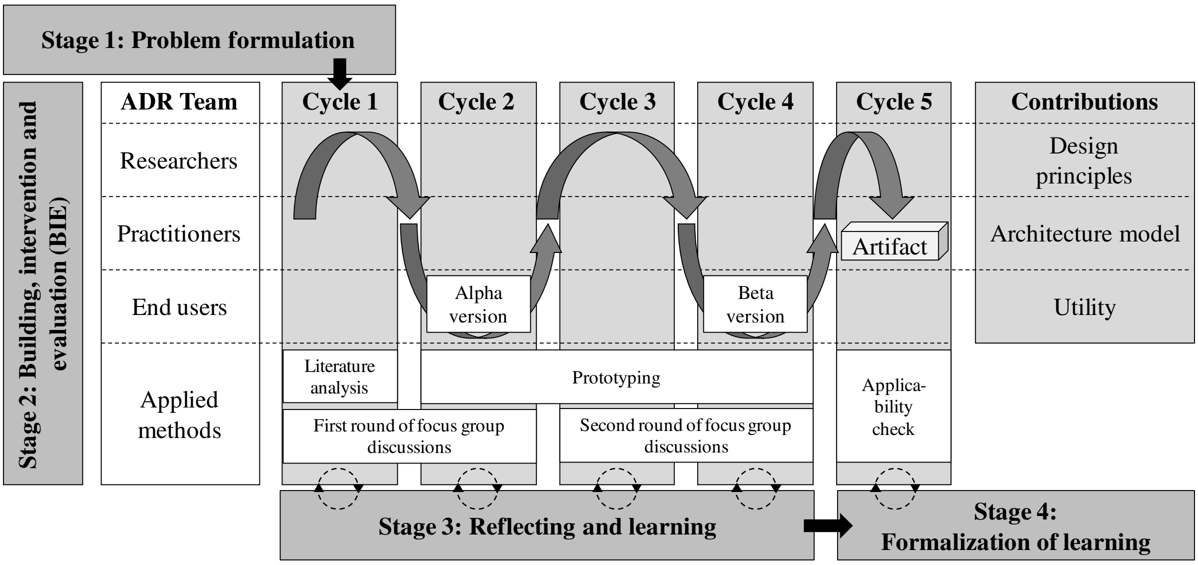

Figure 12. Research design based on the ADR approach from Sein et al. (2011)

The first stage concerns the problem formulation. The problem that forms the basis for subsequent research is identified at an international engineering and manufacturing company. Its objective is to offer smart services that concern the machine availability. Therefore, it is necessary to organize, process and analyze installed base data. An ADR team is built, consisting of researchers from a German university, practitioners from the target company's IT department and product service account management as well as end users from customer service department. In the second stage that is called the building, intervention and evaluation (BIE) stage, five iterative cycles are passed with the objective to continuously build and evaluate the prototype for an information architecture for installed base management. In the first cycle, the alpha version of a prototype is developed referring to a requirements analysis that is conducted. Additionally, a literature search takes place and a series of focus group discussions provides further input. The focus group discussions are carried out with practitioners as well as end users of the future installed base management system (IBMS). The first prototype is presented and evaluated in cycle two, conducting another round of focus group discussions. All investigations and discussions are documented and qualitatively evaluated (Mayring 2015). With the feedback and new findings, the prototype is revised in cycle three, resulting in the beta version. The prototype is tested in cycle four. Real data from the field are used to test the developed information architecture. For a broad evaluation, members of the target company's service product management, service account management, IT application development and IT strategy departments are involved. New insights are used to improve the prototype until the final version of the information architecture is realized (Figure 3). The third stage that is called “reflecting and learning” is carried out together with the second stage. In each cycle that is described, the problem is viewed from different points for a better understanding. In the fourth stage the learning is formalized. A solution is found for a concrete organizational problem. In this stage, findings are abstracted to make the developed architecture generally usable, not limited to the target company. Thereby, general design principles are developed.

3.1.3 Design Principles for an Information Architecture for Installed Base Management

An IBMS enables companies to provide smart services that are related to high machine availability. The challenge is that not all data and information are from the same source nor accessible by a single company (Borchers and Karandikar 2006, Zott et al. 2011). An information architecture supports to work together across companies. Design principles help to establish such information architectures for installed base management (Table 9).

Transparency was named by the focus group as an important factor when talking about installed base management because the architecture should be used by different participants. Subsequent analyses are also facilitated. As information and knowledge from different sources is put together, a consistent vocabulary is necessary. Additionally, a clear structure must be implemented (Wollschlaeger et al. 2015). For example, it has to be clear where information is located to avoid inconsistencies. The different components of the installed base must also be described unequivocally, e.g., by giving each component a unique serial number. The necessity of standardization goes in the same direction. A uniform data format should be determined in order to enable analyses. Thereby, it is important that the data is not only understandable by humans but also by machines. Additionally, the data, information and knowledge should not only be understandable for a single company in a single country but for all participants that are involved. Therefore, internationality is important e.g., regarding date format and language.

Different participants work with the information architecture. Therefore, different perspectives should be enabled that support the different interests. Regarding analyses, machine owners are probably interested in analysis results of their own machines. Component suppliers are interested in results concerning their components, located in different machines. The machine builders are interested in how their machines work. A role-based authentication should be supported by the architecture. As already mentioned, it should be possible to conduct analyses not only for a single component or machine but also across components, machines and plants (Beverungen et al. 2017b). For broad analyses, it must also be possible to analyze unstructured data, e.g., texts. The information architecture for installed base management forms the basis for smart services. Therefore, it must be strongly service-oriented. It should be ensured that new tools can be integrated. The architecture must be dynamic and should easily be adaptable to new requirements.

Table 9. Set of design principles for installed base management

Design principle	Description	Examples	Standards/ best practices
Transparency - Consistent vocabulary - Clear allocation of components - Clear identification of products	It is necessary to have a clear hierarchical structure of the data. The naming should be consistent and generally comprehensible. An unequivocal identification of the products contributes to the clear structure and the creation of a digital twin.	Uniformly named components, serial numbers for unequivocal identification of components	Extensible Markup Language (XML), International Standard Serial Number (ISSN)
Standardization - Uniform data format - Machine readability of the data	A uniform format of the data is necessary for further analyzing. It ensures both that the data is understandable for different target groups and readable by machines.	Uniform sensor data format, enabling exchangeability between companies	eCl@ss
Internationality - International data format - Transferability to other languages	As organizations in the manufacturing industry often operate worldwide, it is of importance that the data has an internationally understandable format. The transferability to other languages should be given.	Uniform date format, multiple language data maintenance	ISO (e. g. date/time ISO 8601)
Perspectives - Adaptable structure depth - Adaptable access rights	The data is used by different participants and by users of smart services. Therefore, a role-based authentication with different read and write permissions is required.	User-dependent view, selective transaction authorization	One-time passwords (OTP), Certified-based authentication (CBA)
Analysis - Across components, machines, plants - Unstructured data	It should be possible to analyze the data, independent on whether they are structured or not.	Comparing the state of different machines, analyzing unstructured comments in text boxes	Apache Hadoop
Service orientation - Tool integration - (near) Real-time data handling	Tools enable individualized smart services. The use of condition monitoring data for smart services requires real-time data handling.	Visualization tools, automated reports, real-time sensor data processing	

3.1.4 Discussion of Results and Enabled Smart Services

Considering the economic perspective, smart services enable continuous revenues (Dreyer et al. 2018b). Looking at the customer, smart services can lead to increasing loyalty as individual requirements are fulfilled (Barrett et al. 2015). New customers can be won and the relation to existing ones can be strengthened. In the manufacturing industry, requirements often concern demands regarding high machine availability (Mert et al. 2016). A prerequisite is to know machines and processes precisely. Only when the behavior of the machines and their current conditions are known, services that go in that direction are reasonable (Kölsch et al. 2017). Therefore, installed base management is necessary. Installed base management provides an overview of the whole installed base that is included. Through a transparent structure of the data, problems can be identified early or even prevented. This contributes to high machine availability. There are also further smart services that are imaginable. For example, optimized maintenance planning is enabled (Olivotti et al. 2018b). Condition monitoring data can be used to identify the current condition of a machine. Maintenance activities can be adapted to that (A detailed presentation of the service approach can be found in Chapter 4.2). Spare parts optimization is also made possible through knowing the current condition of components (Dreyer et al. 2018a). The number of spare parts can be reduced when considering the probability of default of components (A detailed presentation of the service approach can be found in Chapter 4.3). Installed base management enables to see requirements in the short and medium term. Thereby, a strict service orientation is highly recommended.

Smart services that deal with high machine availability only function reliably if a certain data quality is ensured (Sarfi et al. 2012). The best analytical methods can only be successful when the input data is correct. The data quality is therefore an aspect to which attention should be paid (Sarfi et al. 2012). Another aspect is that isolated solutions must be avoided. The information architecture is designed for the usage within a value network, not for a single company. But this means also that the participants of the value network must take part of it. Smart services can only be provided successfully and reliably if information from different participants can be used (Zott et al. 2011). This also has impact on the confidence within the value network.

3.1.5 Limitations, Conclusions and Further Research

In this chapter, design principles for an information architecture were presented. The design principles aim to be generally applicable. Following the ADR process (Sein et al. 2011), the problem that formed the basis for the research came from an organization. Both practitioners and potential end users were involved when the architecture was designed. Two prototypes of the architecture were developed until the final version was reached. Thereby, organizational relevance was ensured. The development of design principles contributed to academic research. The design principles enable to establish installed base management in practice. In turn, this makes the provision of different smart services possible.

The information architecture enables the efficient management of installed base data. Nevertheless, there are some limitations. Although the design principles are developed for different applications, the information architecture from which the design principles were derived was developed within a single use case. Therefore, it cannot be excluded that there are further requirements regarding an information architecture from other companies that are not considered. This is especially true because an information architecture for installed base management is not designed for a single company but for a whole value network. Nevertheless, requirements were not only extracted from focus group discussions in the target company but also from the literature. For further research, it might be interesting to conduct additional studies with other use cases. Related to that, it was focused on the installed base data that were relevant for future smart services of the target company. Within the evaluation, it was ensured that all the installed base data relevant for the target company can be stored through the information architecture. As in the case of the requirements, further companies might have other or additional data. Real-time data were not part of the test run of this study. Therefore, at this state it cannot be said whether the architecture is usable for real-time data such as sensor data. As the amount of real-time data is continually growing, it is recommended to test whether the information architecture is usable for this kind of data. This is focused in a further study that is presented in the following Chapter 3.2. For further research, the information architecture should be tested regarding flexibility and expandability.

Installed base management forms the basis for many different smart services (Gabor et al. 2016). Additionally, digital twins are enabled by that when adding condition monitoring data

(Alam and El Saddik 2017, Gabor et al. 2016, Rosen et al. 2015). The following research study takes installed base management and the developed information architecture as the basis to create digital twins usable for smart services. The same research design is used (i.e. ADR) but further iterative cycles are added.

3.2 Digital Twins for Installed Base Management

The paper called "Creating the foundation for digital twins in the manufacturing industry: an integrated installed base management system" (Olivotti et al. 2019) forms the basis for this chapter (see Appendix A8). It is built on the article "Towards a smart services enabling information architecture for installed base management in manufacturing" on which it was focused in the Chapter 3.1. The article which is considered in this chapter was published in the Information Systems and e-Business Management (ISeB) journal. The focus of the quarterly published journal is on IS in the industry and all topics related to electronic business. Different perspectives are taken, including technological, behavioral and analytical viewpoints. The VHB-Jourqual 3 ranking rates the journal with a "C". The ISeB journal is published at Springer Berlin Heidelberg.

3.2.1 Motivation and Purpose

The generalized information architecture and its design principles were already developed theoretically in the last Chapter 3.1. As installed base management and digital twins are not only interesting for academic research but also in practice, concretely designing and implementing such an information architecture is relevant. In turn, a solution-centered view generates new insights for academic researchers. Coming from the demand of high machine availability (Haider 2011, Mert et al. 2016), providing the possibility of creating digital twins reveals chances. Through a digital twin, installed base data is combined with condition monitoring data (Alam and El Saddik 2017, Gabor et al. 2016, Rosen et al. 2015). But these data and information come from different sources, located at different participants of a value network (Borchers and Karandikar 2006, Zott et al. 2011). This is why an IBMS is necessary where data, information and knowledge is collected and standardized. Although it is undisputed in the literature that digital twins result from input of different sources, the combination e.g., through a platform or management system is rarely considered.

By knowing the current state of a component, a machine or a whole production line, downtimes are reduced and productivity is increased (Kölsch et al. 2017). Therefore, an IBMS is necessary. Providing services that take an IBMS as the basis leads to advantages. Corresponding to that, the following research question is investigated:

RQ 6: How can an integrated installed base management system (IBMS) be designed and implemented in practice?

3.2.2 Research Approach

As this Chapter 3.2 is the continuation of the Chapter 3.1, the ADR approach is used again (Sein et al. 2011). There are also the four typical stages that are carried out during the research process. Stage two consists of several cycles that are carried out successively. In Chapter 3.1 it is stopped after the fifth cycle. Two prototypes were carried out and the final version was presented within cycle five. This is where the research that is presented in this chapter starts. Figure 13 gives an overview of the whole research proceeding.

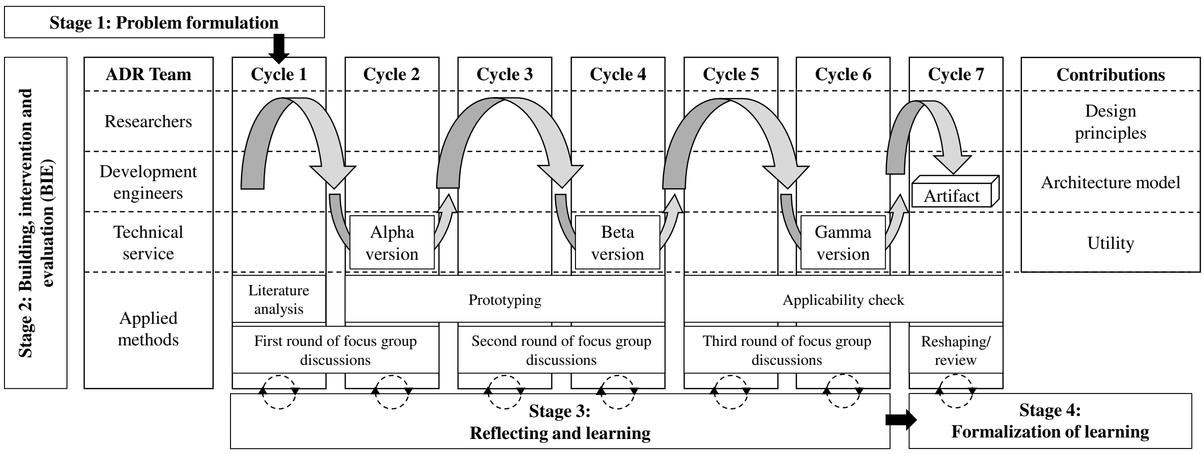

Figure 13. Continued research approach based on Sein et al. (2011)

As the four stages as well as the first four cycles do not differ from the ones already explained in Chapter 3.1, the explanation starts with cycle five. In this cycle, a test case is defined. It results in an extensive applicability check. Before, the performed applicability check did not include condition monitoring data, i.e. sensor data (Dreyer et al. 2017). Therefore, the within this research performed applicability check ensures even more the relevance in practice (Rosemann and Vessey 2008). By using real-time data, the prototype is further improved, resulting in the gamma version. A demonstration machine that is built, functions as the basis for the applicability check. While the machine runs, sensor data is collected and saved according to the information architecture that was already developed. A third round of focus group discussions is conducted through gathering feedback in cycle six. The new findings, both from the applicability check and the focus group discussions are used to further improve the prototype until the final version is reached. While carrying out the different cycles, stage three is again carried out simultaneously. Stage four also works in the same way as before: a broader class of problems is addressed by enhancing the elaborated design principles. The objective is to receive design principles that are generally applicable for those who want to realize digital twins in the manufacturing industry.

3.2.3 Design Principles for Digital Twins in the Manufacturing Industry

Installed base management forms the basis for digital twins (Rosen et al. 2015). Digital twins combine installed base data with real-time data (Alam and El Saddik 2017, Gabor et al. 2016, Rosen et al. 2015). Real-time data are often provided in form of sensor data. In contrast to installed base data, sensor data are frequently updated, resulting in a large amount of data. An information architecture that should be used for digital twins must enable it. In Chapter 3.1, there were already design principles developed, but focusing solely on installed base management, mainly without considering sensor data explicitly. Therefore, five additional design principles are added that should be considered when designing an information architecture both for installed base management and digital twins (Table 10).

Sensor data require a continuous stream between machines and platform (Babcock et al. 2002). Therefore, security and privacy concerns must be considered. In the literature, this aspect in combination with digital twins is rarely considered. Nevertheless, it is discussed in several articles focusing on the IoT. These findings can be adapted to the idea of digital twins. Not only must the data continuously be stored and processed (Li and Parlikad 2016), monitoring results or even controlling machines based on analyses results becomes possible when having digital twins in the manufacturing industry (Qi and Tao 2018). For this aspect, security is also a topic. In the last Chapter 3.1, perspectives were already named as a design principle. This principle is replaced by the term privacy. A role-based authentication is not only necessary for installed base data but also for the resulting digital twin. Tunnel services (e.g., Virtual Private Network (VPN)) are a possibility to ensure a certain level of security and privacy. Data encryption also contributes to that (Mukudu et al. 2016).

Table 10. Additional design principles for an information architecture for digital twins

Design principle	Description	Examples	Standards/ best practices
Security & privacy - Adaptable structure depth - Adaptable access rights	The data is used by different participants and users. Therefore, a role-based authentication with different read and write permissions is required.	Selective transaction authorization	One-time passwords (OTP), Certified-based authentication (CBA)
Infrastructure & technical realization - Suitable interfaces - (Real-time) Data processing	An infrastructure capable of collecting and processing large amounts of data is a necessary precondition for offering installed base management services.	Sensor data collection, production data import, data and information forwarding	Message Queuing Telemetry Transport (MQTT), OPC Unified Architecture (OPC UA)
Scalability - Management of different data volumes - Management of different numbers of sources	Factories can be expanded, or new plants can form part of the installed base. The installed base management must support changes in quantity of data and sources.	Higher frequencies of sensor data, implementation of new machines	
Visualization - Adaptable dashboard - Data/information visualization in real-time	Individualized dashboards show sensor data and further information. All information the digital twin contains are displayable and visualized.	User-dependent view, dashboards, push notifications, intuitive and responsive interface	Hypertext Markup Language (HTML) 5, Cascading Style Sheets (CSS) 3
Value network - Across partners of the network	Installed base management is realized in value networks. All partners must be considered to realize a digital twin.	Component suppliers, machine builders, machine users	Value network analysis (VNA)

Another design principle concerns the IT infrastructure. Sensor data must be stored, processed and analyzed (Li and Parlikad 2016). Depending on the sensor that collects data, the sampling rates might range from many hundreds of times per second and only a few times per day. Therefore, the information architecture that is used must support different requirements. Suitable interfaces must be chosen that fit to the existing infrastructure and are also supported by the information architecture. As in companies ERP systems often contain a lot of installed base data (Borchers and Karandikar 2006), such systems should connectable via interfaces. The same applies for other systems and systems that will become relevant in the future. Therefore, in the case of technical realization, flexibility is highly important.

Having a digital twin for each machine in a production line or a whole plant enables many different services. But for this, it is important that new machines can be added in the system as digital twin. Otherwise, e.g., maintenance planning cannot be conducted efficiently because new machines are not considered. When providing smart services across plants, the same applies for them. Therefore, scalability is important. The platform should not be limited to a certain number of components or machines but extendable flexibly. The number of components or machines also has effects on data streams. Therefore, this should also be scalable.

Visualization is considered as another design principle. The demonstration machine that was used for the applicability check was equipped with a terminal that showed the status of the machine as well as error information. Additionally, a prototype was realized that showed step-by-step instructions in the case of an error. Such visualizations are helpful to ensure high machine availability. The monitoring options were different for different users. Related to the privacy aspect, the information is filtered. Furthermore, different participants of the value network are interested in different information and analyses results. For visualization purposes, flexibility also plays a role because requirements might change in the future.

The already named value network is also included as a design principle. Installed base management in most cases can only be carried out efficiently when different participants work together (Zott et al. 2011). They are able to access different sources and thereby are able to provide different data, information and knowledge. A comprehensive digital twin can only be created within a value network (Zott et al. 2011). The other way round, the resulting digital twins are used in different ways by the different participants. The adjusted visualization is one aspect that should be enabled. Tools that are used by the participants should be includable to e.g., enable specific analyses.

3.2.4 Discussion of Results and Enabled Smart Services

Digital twins are dynamic duplicates of components, machines and production lines (Abramovici et al. 2016). The aspect of dynamic is important because the conditions are continuously changing; this must be represented in the digital twin. Smart services can only be provided successfully when the current condition is known (Fellmann et al. 2011). Reliable digital twins form the basis for many different smart services and business models (Qi and Tao 2018). Many of them base on the idea of high machine availability. Nevertheless, the design can be very different. Two possible approaches for smart services that base on the idea of installed base management and digital twins are presented in the Chapters 4.2 and 4.3. Predictive maintenance forms the basis for both approaches. For example, maintenance planning is adapted to the current conditions of machines (Olivotti et al. 2018b). Thereby, too frequent maintenance activities are avoided and money is saved. Additionally, it is ensured that machines are maintained that show anomalies.

In most cases, digital twins are only comprehensive when different participants of a value network are involved (Zott et al. 2011). Depending on the field of activity, the participants have different data sources and information. Only when data, information and knowledge from different sources come together, a comprehensive image can be created. This might lead to the fact, that only some of the participants use the digital twins to offer smart services. To not exploit the other participants, regulations must be enacted. For example, it can be realized by agreeing on a fee for using the data. Another possibility is that analysis results are also shared with those who have no direct contact with the customer.

The developed design principles help to form the basis for digital twins by implementing an information architecture. But it cannot be said how the requirements will look like in the future. It is pointed out that the information architecture must be flexible to be suitable in the future. But as future requirements and needs are not known now, it cannot be ensured how a suitable information architecture will look like. Nevertheless, the design principles do not only refer to a specific company or a specific application but address a broader class of problems. Thereby, it is detached from concrete application scenarios.

3.2.5 Limitations, Conclusions and Further Research

In the manufacturing industry, there is a shift in emphasis away from selling solely products to also offer services (Neff et al. 2013, Oliva and Kallenberg 2003, Schrödl and Bensch 2013). Usually, these are smart services that are adapted to individual customer needs (Calza et al. 2015). Thereby, relationships to customers are strengthened (Rabetino et al. 2017). To be able to offer smart services in the manufacturing industry and to realize related business models, digital twins are necessary (Qi and Tao 2018). A suitable information architecture forms the basis for it. Therefore, design principles were developed to realize such an information architecture. For installed base management, there were already several design principles developed in Chapter 3.1. Within this chapter, five additional design principles were investigated that also consider condition monitoring data, such as sensor data. The other already presented design principles are also relevant for digital twins.

The research proceeding was oriented on the ADR approach, established by Sein et al. (2011). The approach ensures practical relevance by stipulating continuous interaction between researchers, practitioners and potential end users. The organizational problem that was considered came from a manufacturing company. The requirements were taken up in the same company. The same applies for the focus group discussions. Although a broader class of problems was addressed through the design principles, the initial assumptions came from a single company, the target company. For further research it would be interesting to expand the cycle of involved participants. This would contribute to the idea that the whole value network should be integrated. Nevertheless, existing research was also considered to aim general applicability.

An applicability check in form of a test run forms part of the research proceeding (Rosemann and Vessey 2008). Real data from the field were used to test the information architecture. Within the test run, it was confirmed that different types of data can be standardized and stored through the information architecture. Predictive maintenance applications were chosen as application scenario. For further research, additional applications should be tested to ensure an information architecture that is useful for many different types of applications and services. Furthermore, in the test case only one machine was included. The extensibility and flexibility of the information architecture should also be tested by creating several digital twins from different components and machines.

4 Smart Services Based on Predictive Maintenance

In the manufacturing industry, smart services that base on the idea of predictive maintenance are mainly disseminated (Edwards et al. 1998). Therefore, the approaches that are presented in the following focus on smart predictive maintenance services in the manufacturing industry. But first, the concept of predictive maintenance is described, based on the second section of Paßlick et al. (2019).

Predictive maintenance services are service solutions that aim at optimizing maintenance activities, always adapted to specific use cases (Zoll et al. 2018). Predictive maintenance is mostly applied in the manufacturing industry (Edwards et al. 1998). The production processes are more and more optimized there which is why machine breakdowns must be prevented (Mattes and Scheibelhofer 2012).

Although predictive maintenance is already named as promising service concept some decades ago (Amruthnath and Gupta 2018) it is increasingly focused on it within the context of the digital transformation (Cachada et al. 2018, Zoll et al. 2018). The idea of predictive maintenance is to know the current state of all important components and whole machines in order to predict the remaining lifetime (Li et al. 2005, Liao et al. 2012). Thereby, breakdowns of machines are avoided and intelligent maintenance planning is enabled. Additionally, predictive maintenance can contribute to strategic goals of a company (Nadj et al. 2016).

The objective of predictive maintenance is not only to measure predefined sensor data and to compare it to target values (Jezzini et al. 2013). Correlating different values and analyzing them in connection with data from further machines, e.g., using stochastic methods (Zhao et al. 2010), also forms part of reliable predictive maintenance. Thereby, detection, identification and tracking of rising failures are enabled (Yuan et al. 2013).

Predictive maintenance is determined as the most comprehensive form of maintenance that is enabled by data (Paßlick et al. 2019). It includes reactive maintenance what means that activities are performed when failures occur (Susto et al. 2012). Condition-based maintenance also forms part of predictive maintenance (Araiza 2004). Condition-based maintenance looks at the current state of a component or machine in order to decide if maintenance activities are necessary (Susto et al. 2012). Statistics-based predictive maintenance, also called prognostic-based maintenance (Araiza 2004), looks at the expected future state as basis for decisions (Edwards et al. 1998). Prediction tools and different methods are used to predict the trend of the state of a component or machine (Susto et al. 2012). Building on this, maintenance activities can be planned and continually adapted.

As it is typical for smart services, predictive maintenance is enabled by large volume of data (Borgi et al. 2017) and their collection, transmission and analysis in (near) real-time (Cachada et al. 2018, Wang et al. 2017). It is necessary to have a comprehensive overview of the current conditions of components or machines to be able to offer a smart predictive maintenance service (Hui et al. 2008). The start of degradation should be detected as early as possible (Borgi et al. 2017, Khazraei and Deuse 2011). Therefore, different types of data must be collected and related to each other. Sensors are an important source for condition-related data (Sipos et al. 2014). These data and information are processed, e.g., through vibration analysis, thermal images (Barbera et al. 1996), trend analysis and simulation (Aivaliotis et al. 2017). But also information such as design, application and the maintenance history are information sources for decisions (Darwanto et al. 2012). Optimum maintenance activities are derived from that within a service, always adapted to the individual context of the customer.

4.1 Describing Predictive Maintenance within a Taxonomy

This chapter is based on the article called "Predictive maintenance as an IoT enabled business model: towards a taxonomy" (Passlick et al. 2019) that is submitted to the Electronic Markets Journal for the special issue on "Internet of Things for electronic markets" (see Appendix A11). The special issue concerns all topics in the IS research field that are related to the IoT. IoT enables to connect devices in a new way leading to novel applications. As IoT is a relatively recent development, there are many interesting points for research. For example, the role of cyber-physical systems in electronic markets is a suggested topic. Another field that is highlighted by the editors is business models and services. On the one hand, it is suggested to investigate IoT services within the supply chain management. On the other hand, business models based on IoT are named as an interesting starting point for further research. Within the VHB-Ranking, the Electronic Markets Journal is rated with a "B".

4.1.1 Motivation and Purpose

Predictive maintenance forms the basis for many different business models (Zoll et al. 2018). Many companies already offer predictive maintenance services or plan to offer it in the future. A study showed that out of 280 companies that were investigated, 184 want to offer predictive maintenance services or already offer it (PricewaterhouseCoopers 2017). Different business models are imaginable to optimize maintenance activities at the customer’s side. From a customer perspective, it is difficult to compare different predictive maintenance offers. But also for the comparison with competitors it is important to understand the different business models to enable long-term success (Dijkman et al. 2015). Growth opportunities and unique selling points could then be identified by providers. For researchers it is also relevant to understand how predictive maintenance business models are configured. The reason is that in the scientific field the interest in predictive maintenance is increasing (Daily and Peterson 2017).

In order to systematize predictive maintenance business models, a taxonomy is helpful that reflects the most important characteristics of predictive maintenance business models. Additionally, the relations between the different characteristics are revealed (Glass and Vessey 1995). In other fields, taxonomies were already used for structuring purpose (e.g., Gimpel et al. 2017, Täuscher and Laudien 2018). Therefore, the following research question is answered within this chapter:

RQ 7: How does a taxonomy for predictive maintenance business models look like?

The developed taxonomy classifies existing business models for predictive maintenance. It shows the diversity of predictive maintenance business models by considering 113 different companies all over the world. Clusters of similar business models are figured out by using a visualization procedure that is based on an autoencoder application.

4.1.2 Research Approach

The development of the taxonomy is based on the approach presented by Nickerson et al. (2013). Figure 14 summarizes the described proceeding. Looking at the first step, the meta characteristic of a taxonomy describes the focus of the taxonomy and is the basis for the decision of dimensions and characteristics. In this research, the meta characteristic is the definition of elements of predictive maintenance business models. Scientific literature related to business models is examined to identify dimensions of the taxonomy. After that, 113 companies that are globally distributed form the basis to identify the characteristics of the dimensions. The characteristics that refer to a dimension are exclusive (Nickerson et al. 2013). This means that exactly one characteristic is suitable for a business model when looking at a single dimension.

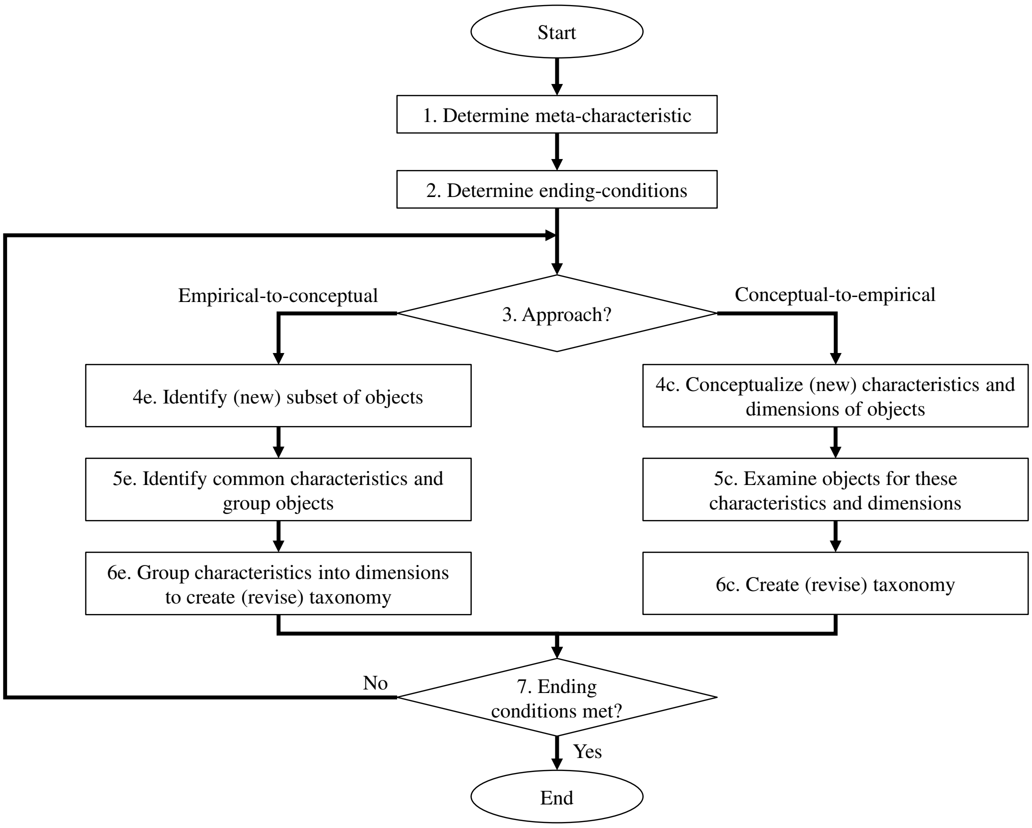

Figure 14. Taxonomy development procedure by Nickerson et al. (2013)

According to Nickerson et al. (2013), several iterations are conducted until the final version of the taxonomy is reached. For all iterations it must be decided which approach of two possible ones is taken: conceptual-to-empirical or empirical-to-conceptual. In the case of the first one, the taxonomy is adapted with basis on concepts, e.g., in form of already existing models. The other approach is based on empirical data. End conditions are adapted from Nickerson et al. (2013) and can be read in the appendix of the article on which this chapter bases (Passlick et al. 2019). After each iteration, the end conditions are checked and it is decided whether a further iteration is necessary.

In the first iteration, a conceptual-to-empirical approach is taken. Within this iteration, the framework for the taxonomy to be developed is elaborated. Therefore, elements of electronic business models are reviewed. Research results presented by Afauh and Tucci

(2001), Alt and Zimmermann (2001), Brousseau and Pénard (2007), Mahadevan (2000), Osterwalder and Pigneur (2010) are compared to each other. It turns out that the approach called “Business Model Canvas” by Osterwalder and Pigneur (2010) summarizes the most important elements of business models that are named in the literature. Therefore, the Business Model Canvas forms the basis for the dimensions of the taxonomy. Each element that is named by Osterwalder and Pigneur (2010) is reviewed regarding its importance for the taxonomy. Some of the elements are determined to be not relevant because most of the predictive maintenance business models would have the same characteristic (e.g., key resources). There are also some elements that are filtered out because the characteristics cannot be figured out by looking at the company’s website (e.g., key partners). At the end of the first iteration, five dimensions are identified: key activities, value proposition, revenue streams, sales channel and customer segment. As many end conditions are not fulfilled after the first iteration, a further iteration is necessary.

The empirical-to-conceptual approach is chosen for the second iteration. Data from companies is analyzed that offer predictive maintenance services. In total, 42 interviews are conducted with representatives of 42 companies. The knowledge gained in the first iteration forms the basis for the interviews. Additionally, Google searches are conducted to identify further companies that offer predictive maintenance services. As a result, further 29 companies are included. The Crunchbase website, a database that summarizes information about companies, is also considered for the identification of relevant companies. Filtering the short descriptions by using the terms “predictive maintenance” and “condition monitoring”, 42 additional companies are figured out (A list of all 113 companies is presented in the appendix of Passlick et al. 2019.).

Ten companies are selected arbitrarily for the second iteration. For each of the ten companies, the suitable characteristics for the different dimensions are derived. Thereby, similar characteristics are summarized (e.g., the production of hardware components for sensor technology, networking and electronic is summed up in the characteristic “hardware development”). While conducting the second iteration, a further dimension is identified that is considered to be interesting for predictive maintenance business models: clients. Thereby, the target group of the service is defined. Additionally, the technical layer to which a company refers is added as a dimension. The layers that are described in IoT architecture models (e.g., Chen 2013, Turber et al. 2014) are addressed by the named dimension. As the end conditions are not met after the second iteration, another one follows.

Empirical-to-conceptual is again chosen for the third iteration. A sample of 20 further companies is taken. It is checked whether the dimensions and characteristics that are worked out in the first two iterations are also suitable for further predictive maintenance business models. It turns out that some changes have to be made. For example, the provision of infrastructures, platforms and software are combined in “provision of a public cloud”. But the largest changes are conducted in the dimension “revenue stream”. It is renamed with “payment model” and reflects the pricing strategy of the predictive maintenance service (e.g., one-time payment, project payment, on usage basis). Furthermore, the dimension “sales channel” is renamed into “deployment channel”. It is determined to be more interesting how a customer accesses a service than how it is bought. Significant changes are made in the third iteration, indicating that an additional iteration is necessary.

In the fourth iteration, also proceeding empirical-to-conceptual, 30 additional companies are examined. It is found that large companies (e.g., Bosch Rexroth) mostly do not only have a single key activity. Therefore, “universal range” is added as characteristic for those companies. Another change that is conducted in the taxonomy is that “logistics/transport industry” is added as characteristic of the dimension “customer segment”. “Manufacturing industry + energy sector” is also added there. Although there are no fundamental modifications, some characteristics are added. Therefore, another round of iteration is carried out.

For the fifth iteration, in which it is also worked with the empirical-to-conceptual approach, the remaining 53 companies are examined. It turns out that the already developed dimensions and characteristics are appropriate to describe the predictive maintenance business models of the 53 companies. According to Nickerson et al. (2013), all end conditions are fulfilled and the final taxonomy is reached.

4.1.3 Taxonomy for Predictive Maintenance Business Models and Archetypes

In total, seven dimensions are identified for the predictive maintenance business model taxonomy. One of the dimensions is key activities. It focuses on what the company primarily does concerning their predictive maintenance business model (Osterwalder et al. 2005, Osterwalder and Pigneur 2010). The dimension called “value promise” describes how the requirements of the customers are met (e.g., through automation or forecasting) (Osterwalder et al. 2005, Osterwalder and Pigneur 2010). The payment model concerns the pricing strategy that is used within the predictive maintenance business model. How predictive maintenance is provided is reflected in the dimension “deployment channel”. The target industry is concerned through “customer segment”, another dimension that forms part of the taxonomy. The type of clients (e.g., B2B or B2B + state) is considered in another dimension. The last of in total seven dimensions is the information layer. It reflects the area in which a service is provided, based on Chen (2013). Table 11 depicts the whole taxonomy.

Table 11. Developed taxonomy for predictive maintenance business models

Dimensions	Characteristics
Key activities	Hardware development, software development, consulting, edge computer development, provision of a public cloud, hardware retailer, universal range, provision of an application platform
Value promise	All-in-one solution, condition monitoring, connectivity, automation, forecasting, data security, data storage + software development tools
Payment model	One-time sales, time basis, Project, usage basis, hybrid
Deployment channel	Physically, www, physically + www (cloud), www (cloud) + API, www (cloud), physically + www (cloud) + API
Customer segment	Manufacturing industry, energy sector, no industry focus, high-security areas, manufacturing industry + energy sector, manufacturing industry + logistics/transport industry
Clients	B2B, B2B + B2B2B, B2B + state
Information layer	Application and services, information handling, information delivering layer, object sensing and information gathering layer, multiple

After developing the taxonomy, archetypes are worked out that represent typical predictive maintenance business models in a general way. Both a dendrogram and autoencoder techniques (Hinton and Salakhutdinov 2006) are used to identify the archetypes. This leads to six archetypes that are figured out. Mainly, they are named after the key activities that they offer.

The first archetype is “hardware development” and fits with 21 % of the business models in the sample of 113 companies. In addition to the hardware developers, some of the companies that provide edge devices are also included here. Mainly, their value proposition is condition monitoring. One-time sales usually form the basis of the pricing strategy. This is comprehensible because hardware is provided instead of a service. Accordingly, the deployment channel is physically. There is no focus on a specific industry but it can be said that the client relationship is B2B. Regarding the information layer, “object sensing and information gathering” is the most common one.

The second archetype that includes 12 % of the sample is “platform provider”. It is focused on forecasting models whereby a hybrid payment model is realized. This is because some companies offer consulting services and hardware devices in addition to an application platform. This is also the reason why the deployment channels are both physically and via cloud. It is mainly focused on the manufacturing industry which is why B2B relationships are common. The companies with business models that correspond to the platform provider archetype mainly operate in the application and services layer.

The “all-in-one” archetype is appropriate for 27 % of the companies of the sample and forms the largest group. The key activities are universal offers and the payment model is hybrid. This is because the value promise is comprehensive and includes services and products. This is also why the deployment channel is both physically and via a cloud platform. The customer segment cannot be specified but the customers’ relationship mainly is B2B. The information layer that is considered by this archetype can neither be specified.

With 5 % of the sample, the “information manager” archetype is the rarest one. Its key activity is edge computer development while the value promise mainly concerns condition monitoring. The payment model is also hybrid and the deployment channel is also physically and via cloud. The business models of these archetypes are mostly tailored for the manufacturing industry. But thereby, not only B2B relationships are concerned but also business-to-business-to-business (B2B2B) relationships. Many of the companies that belong to the information manager archetype are active in multiple information layers. But there is also a significant share that concentrates on information delivering.

The fifth archetype is “consulting” and includes 13 % of the companies in the sample. The consulting activities mainly concern condition monitoring. As usual, consulting activities are billed project-based. The deployment channel is physically because consulting activities cannot be provided automatically via a cloud platform. B2B customers are addressed by this archetype, but not focusing on a specific branch. “Application and services” is the information layer that is mainly concerned. By some companies of that archetype multiple layers are considered.

The last archetype that was figured out is the “analytics provider”, uniting 20 % of the companies of the sample. The key activity is software development, sometimes application platforms are provided. The main value promise is forecasting, matching with analytics. The analytics provider is the only archetype that prefers a payment model on a time basis. The service is provided via a cloud platform. It is not focused on a specific industry but the customers are in the B2B segment. “Application and services” is the most common information layer that is considered but information handling also plays a role. Table 12 summarizes the six archetypes.

Table 12. Identified architypes of predictive maintenance business models

	Archetype					
Label	**Hardware development**	**Platform provider**	**All-in-one**	**Information manager**	**Consulting**	**Analytics provider**
Key activities	Hardware development	Provision of an application platform	Universal offer	Edge computer develop-ment	Consulting	Software develop-ment
Value promise	Condition monitoring	Forecasting	All-in-one solution	Condition monitoring	Condition monitoring	Forecasting
Payment model	One-time sales	Hybrid	Hybrid	Hybrid	Project	Time basis
Deployment channel	Physically	Physically + www (cloud)	Physically + www (cloud)	Physically + www (cloud)	Physically	www (cloud)
Customer segment	No industry focus	Manufactur ing industry	No industry focus	Manufacturi ng Industry	No industry focus	No industry focus
Clients	B2B	B2B	B2B	B2B + B2B2B	B2B	B2B
Information layer	Object sensing and information gathering	Application and services	Multiple	Multiple & information delivering	Applicatio n and services	Application and services & information handling
Share in sample (113)*	21%	12%	27%	5%	13%	20%
Example company	Rockwell Automation	Test Motors	National Instruments	IXON	Hitachi Consulting	Senseye

*Due to rounding inaccuracy the sum is not exactly 100%.

4.1.4 Discussion of Results and Implications

A taxonomy was developed for predictive maintenance business models. Looking at other classifications of business models in the field of IoT, there are some similarities. Value proposition and key activities are dimensions that are often named (e.g., Eickhoff et al. 2017, Hartmann et al. 2016, Täuscher & Laudien 2018). The found archetypes developed from the taxonomy offer similarities to the archetypes of data-driven business models, presented by Hartmann et al. (2016). In both business model frameworks data plays a decisive role. In the case of the taxonomy for predictive maintenance business models it is represented by the dimension concerning the information layer. Hartmann et al. (2016) do more focus on the data sources. The data sources were not considered within the developed taxonomy because the data is mainly provided by the customers.

While working through the sample, it turned out that several companies face the problem of old machines at the customers' side. These machines are not appropriate to be included in predictive maintenance activities because technical requirements are not given. These companies mostly belong to the "hardware development" archetype. They provide hardware to enable data collection and analysis. "All-in-one" companies also address the problem of old machines. They offer both software and hardware to be able to monitor those machines.

From a theoretic perspective, the taxonomy enables to better understand how business models for predictive maintenance are structured and how they differ from other types of business models. Taking a practical view, the taxonomy provides an inside in different dimensions that should be considered when designing a predictive maintenance business model. Additionally, approaches are enabled to compare different business models. A company can evaluate whether a planned new business model is common or not. The six archetypes contribute to that.

"Information manager" is the smallest group in the sample. One reason could be that this business model approach is not highly demanded by the market. It is also possible that companies that do not belong to this archetype provide similar offers, compared with additional value propositions. Another reason might be that an information manager is not limited to the area of predictive maintenance. All business model approaches that come from the field of IoT deal with large amount of data and information. Therefore, it is possible that most of the companies that are information managers do not promote it in combination with condition monitoring and predictive maintenance but in a more general way.

4.1.5 Limitations, Conclusions and Further Research

A taxonomy was developed that classifies business model approaches around predictive maintenance. Seven dimensions were identified with different possible characteristics. Thereby, not only general aspects of the Business Model Canvas (Osterwalder & Pigneur 2010) were considered, but also the aspect of information layers (Chen 2013). All four layers that are presented by Chen (2013) are included for predictive maintenance services. A cluster analysis was used to figure out six archetypes (Ward 1963).

Although the taxonomy gives a structured insight in business model approaches for predictive maintenance, there are some limitations. The sample of 113 companies was set up based on the definition for predictive maintenance presented in Chapter 4. By using another definition, the sample might have consisted of less, other or additional companies. This would have had impact on the taxonomy that was developed. For the identification of the companies, different databases were used. Nevertheless, there are more databases containing structured information about companies that were not considered. For further research, additional databases should be included in order to expand the sample. Another approach to expand the sample is using additional search terms. For the identification of potential relevant companies, the two search terms “predictive maintenance” and “condition monitoring” were used. Other search terms might lead to further results. With a larger sample, statistical analyses become more stable.

Companies that were on the market at that time were included in the sample to develop the taxonomy. Therefore, the taxonomy and the identified archetypes can be seen as a snapshot taken at a specific time. There are not yet established structures and processes. New business models are developed, realized and tested if they can survive on the market. The development of new technologies can change the market significantly. This is the reason why it cannot be excluded that the taxonomy must be adapted in the future. Nevertheless, the taxonomy and the archetypes enable to better understand how predictive maintenance business models are structured, both from a theoretical and practical perspective.

4.2 Individual and Dynamic Maintenance Planning

This chapter is based on the article “Maintenance planning using condition monitoring data” by Olivotti et al. (2018b) that was presented at the “OR2017 — Annual International

Conference of the German Operations Research Society" (see Appendix A3). The article was subsequently published in the Operations Research Proceedings 2017. The conference took place from September, 06 to 08, 2017, in Berlin at Freie Universiät Berlin. The annual conference for academics and practitioners focuses on research insights in the fields of operations research (OR), management science, data science and analytics. The main theme of the conference in 2017 was „Decision analytics for the digital economy".

4.2.1 Motivation and Purpose

Predictive maintenance uses condition monitoring data and further information to plan maintenance activities (Last et al. 2010). Often, maintenance activities are performed based on predefined schedules, e.g., provided by the machine manufacturer (Khazraei and Deuse 2011, Sipos et al. 2014). When considering the current state of the machines in a production, time, effort and costs are reduced (Chu et al. 1998). On the one hand, too frequent maintenance activities are avoided. On the other hand, when maintenance activities are carried out too rarely the probability of machine breakdowns is increased. Sensor data can be used to define the optimum maintenance intervals (Peng et al. 2010). Thereby, not only the optimum maintenance interval for a single machine must be considered but put in the context with the other machines in a production (Bouvard et al. 2011). The reason is that maintenance activities are often carried out externally or by specific internal teams that are responsible for several production lines and locations. Therefore, travel costs and further one-time costs must be considered (Wildeman et al. 1997). The result is that the maintenance intervals are not necessarily optimal for a single machine but for the whole production by grouping maintenance activities. In practice, it is challenging to combine condition monitoring data with suitable prediction models and algorithms (Kaiser and Gabraeel 2009, Kothamasu et al. 2006). In order to plan suitable maintenance activities, a procedure that contains an optimization model is necessary that minimizes the costs. Therefore, the following research question is examined:

RQ 8: How can maintenance schedules be optimized using condition monitoring data?

A procedure is developed where a balance can be found between maintenance costs and possible breakdown costs, for several machines. Condition monitoring data is considered to forecast maintenance activities for multiple periods. A trade-off results between grouping maintenance activities of several machines to safe fixed costs and the deviation of a single machine from the individual optimum maintenance time.

4.2.2 Procedure to Determine Optimal Maintenance Activities

The presented procedure enables to plan maintenance activities for several periods considering multiple machines. Thereby, maintenance activities are grouped in order to reduce fixed costs. The procedure, including six steps that are described in the following, comprises an algorithm in connection with an optimization model. In the first step, input parameters must be set. These include the downtime costs of each machine, fixed maintenance costs per group and the maintenance costs of each machine. The probability of default of the different machines is also an input parameter. In the second step, all combinations of machine groups are determined through an algorithm. Thereby, only machines are included which need to be maintained in the considered time horizon. The number of groups is not predefined. So, one possible combination is that every machine has its own group. The other extreme is that all machines are in the same group and so are maintained together. All possible cases between these two extremes are also imaginable. Maintenance groups are built because it is assumed that machines with a similar optimal time for maintenance are maintained together. Therefore, the machines are sorted according to their individual optimum maintenance time. In the fourth step, all to the group related parameters must be identified. It includes for example the number of machines in a group and the total costs of a group. Then, the optimization model can be run to determine the minimal costs (The mathematical model can be found in the article from Olivotti et al. 2018b.). Thereby, all possible group combinations are considered and the combination case with the lowest costs is figured out. Hence, the related maintenance plan can be derived in the last step of the procedure. Figure 15 summarized the procedure to determine optimal maintenance activities.

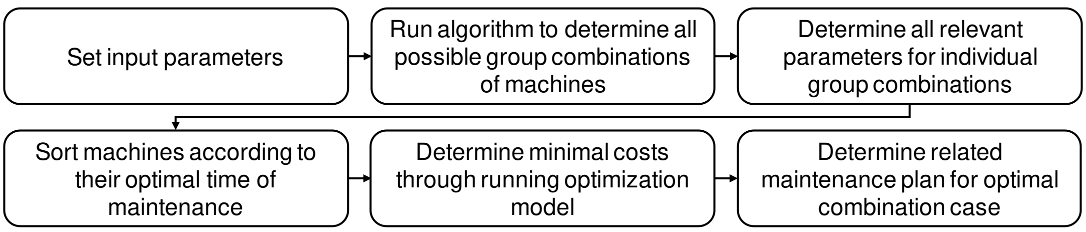

Figure 15. General procedure to determine optimal maintenance activities

4.2.3 Discussion and Business Model Approach

Determining time schedules for maintenance activities is an important part of predictive maintenance (You 2017). The presented procedure enables to optimize maintenance planning through using condition monitoring data. Nevertheless, the procedure does not cover the whole cycle of predictive maintenance that begins with analyzing condition monitoring data. Within the procedure, it is started with determining the optimum maintenance times of the groups. Thereby, the ideal time to maintain an individual machine is already known. It is a possible starting point for further research to extend the procedure with the determination of the individual optimum maintenance time of a machine. Another part of the procedure that could be optimized is the maximum number of maintenance events. Within the model, there is not a restriction regarding the maximum number of groups and thereby a maximum number of maintenance periods. Assuming that maintenance activities are not carried out by employees of the company but by an external service provider, the number of times a service employee comes around might be limited. Therefore, it would be a useful extension to integrate a restriction for the number of groups. That might especially be helpful in practice.

The presented optimization model can be used by service providers that carry out maintenance activities. A business model approach is that the service is not only to carry out the activities but also to optimize maintenance plans. Thereby, the company that owns the machines can save money. A business model approach could be that the service provider is participating on the saved money. For example, 50 % of the saved money is for the service provider and the other 50 % is for the machine owner. The advantage for the machine owner is that the maintenance activities are optimized. On the one hand, this means that machine downtimes resulting from maintenance activities are reduced because the maintenance schedule considers the condition of the machines. On the other hand, costs are saved, for the same reason. Condition monitoring data is used and unnecessary maintenance activities are avoided. From the service provider's view, new revenue streams are realized. Additionally, customer relationships are strengthened because an individually adapted smart service is provided (Berman 2012, Rabetino et al. 2017). This can lead to a unique selling point.

4.2.4 Limitations, Conclusions and Further Research

The presented procedure enables to calculate an optimum maintenance schedule, considering condition monitoring data. Using an optimization model, the costs are reduced. Thereby, it is balanced between potential maintenance costs and costs for too late or too early maintenance activities. A limitation is that the number of possible group combinations is rising exponentially with a rising number of machines that are considered. Therefore, the calculation effort also rises exponentially. An approach would be to not consider individual machines but groups containing machines with similar optimum maintenance times. The groups are again summarized into groups. Working out this approach is interesting for further research. Another limitation is that probabilities of default are used in the model for further calculations. In the case of predictive maintenance, the main source of data to determine the current condition is sensors. Therefore, the quality of the sensor data is essential for the subsequent calculated probability of default. The quality of the data related to the breakdown costs is also important. Apart from optimizing the procedure further it might also be interesting to develop an interface for those who work with the optimization model. This is especially interesting for those in practice.

The presented procedure can be seen as a starting point for further research. It already shows how maintenance schedules can be optimized considering the current condition of machines. It is not only looked at a single machine but at many different machines that must be maintained within a defined period. It is considered that it is useful to group maintenance activities to reduce fixed costs (Wildeman et al. 1997). This is especially important when maintenance activities are carried out by service providers. The presented business model approach is for service providers that not only want to carry out maintenance activities but want to strengthen customer relationships through a smart service.

4.3 Continuous Spare Parts Optimization

This chapter is based on the article “Optimizing machine spare parts inventory using condition monitoring data” by Dreyer et al. (2018a) (see Appendix A2). The article was presented at the “OR2016 — Annual International Conference of the German Operations Research Society” and published in the conference proceedings. The conference took place from August 30 to September 02, 2016, in Hamburg at the Helmut-Schmidt-Universität. The theme of the conference in 2016 was „Analytical decision making“.

4.3.1 Motivation and Purpose

Along with the high requirements regarding machine availability, the optimization of spare parts management becomes a topic (Jalil et al. 2011). Each spare part means capital commitment. Therefore, companies aim in optimizing spare parts inventory (Dombrowski and Fochler 2018). At the same time, they could not risk that a necessary spare part is not stored. Therefore, it is interesting to identify the optimum number of spare parts by balancing risks and costs (Yang and Niu 2009). This leads to the following research question:

RQ 9: How can a spare parts inventory be optimized using condition monitoring data?

In the manufacturing environment, several machines are located at the same place. Although they might have different functions, there are types of components that can be found in different machines. This leads to the fact that a spare part can potentially used for different machines. In this case, it is not necessary to store a spare part for each machine. Depending on the risk of a machine downtime, the optimum number of a specific spare part can be determined, being between zero and the number of installed components of that type. Several factors influence the optimum number. Important influencing factors are e.g., failure probability, provision costs and the number of installed components. The named factors are considered within an optimization model. The failure probability is determined for each component built in a machine. In order to make the forecast as precise as possible, data from condition monitoring processes are considered. This data contains both sensor data as well as empirical values. Together with further influencing factors, a decision support system is elaborated. It forms the basis for different business models.

4.3.2 Procedure to Determine the Optimal Number of Available Spare Parts

In order to optimize the spare parts inventory, an optimization model is developed. It is a combination of a stochastic model and an algorithm. Within this model, the recommended amount of spare parts for a specific type of component is determined. The model optimizes the sum of provision costs and the expected downtime costs with the number of spare parts as the variable. The optimization model is the basis for a procedure with five steps that is described in the following (The optimization model itself can be found in Dreyer et al. 2018a).

In the first step of the procedure, several input parameters must be set. Exemplary input parameters are the provision costs for one spare part, the probability of default resulting from empirical values and the probability of default resulting from sensor data. The two probabilities are weighted. It is assumed that at the end of each period it is checked whether there are defective components. Within a period, there is no control that takes place. Thereby, it is possible to use the available spare parts preferably for the defective machines with the highest downtime costs. All possible combinations of faultless and defective components are determined in the second step. It can be visualized through a decision tree where each branch describes one possible combination that can be found at the end of a period. Within the decision tree, the components in the branch are sorted from the highest to the lowest downtime costs.

The combinations are used in the third step for the algorithm. The algorithm determines all relevant probabilities. An important value is the probability that the downtime costs of a component occur, assuming a specific number of spare parts. When all values are determined, the optimization model can be run and thereby the minimal costs can be calculated. The associated optimum number of spare parts can be determined in the last step of the procedure. A summary of the procedure is shown in the following Figure 16.

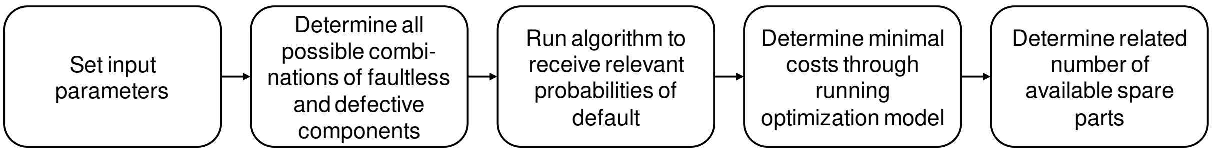

Figure 16. General procedure to determine the optimal number of available spare parts

4.3.3 Discussion and Business Model Approach

The algorithm enables to determine the optimum number of spare parts under consideration of condition monitoring data. Therefore, it is not necessary to use only empirical data. Nevertheless, empirical data is not omitted when calculating the number of spare parts. A weighting factor enables to determine how important this data is, in comparison to condition monitoring data. In the case that the empirical data is weighed with a 1, the highest possible weight, it is even possible to use the optimization model when no condition monitoring data is available.

Spare parts optimization can be seen as part of predictive maintenance (Mustakerov and Borissova 2013). When planning maintenance activities in practice, an inventory with enough spare parts is necessary to ensure high machine availability. Therefore, the optimization of the spare parts inventory should not be considered in isolation but together with maintenance activities. Thereby, it is advantageous that the optimization model is carried out periodically. On the one hand, this enables to consider the current condition of a component. On the other hand, it can be adapted to the maintenance planning. This means that the period length in which the maintenance activities are updated can be applied to the spare parts calculation.

The presented procedure to determine the optimum number of spare parts forms the basis for a novel business model. The service idea is that the customer is able to adapt the number of spare parts in each period. Usually, the customer must buy a spare part. Thereby, it is part of the inventory until it is used (Chang et al. 2005). But in the new business model, the customer does not buy the spare part but pays for the provision of it. A lump-sum fee is paid for one period. After the period ends the customer can decide whether it should stay in the inventory or not. Through the optimization model in conjunction with the algorithm it is calculated at the end of each period how many spare parts should be in stock. As the number cannot only rise but also decline, the service idea enables the customer to have the optimum number of spare parts in every period. This reduces the risks of machine downtimes. Additionally, fixed capital is reduced.

4.3.4 Limitations, Conclusions and Further Research

An optimization model in conjunction with an algorithm enables to determine the optimum number of spare parts. The total costs are minimized, including both expected downtime costs and provision costs. Condition monitoring data and empirical data are considered and thereby contribute to predictive maintenance service offers. A business model approach was presented in which the optimization model forms the basis. Instead of buying the spare parts, the customer pays a lump-sum fee for the provision of a spare part for one period. Thereby, it is possible to adapt the number of spare parts in both directions in each period.

Refining the business model approach and elaborating a concrete business model would be interesting, especially for those in practice.

A limitation of the process is that all possible combinations of faultless and defective components must be determined. The number of possibilities is rising exponentially with the number of components what leads to an exponentially rising calculation time. A possibility would be to not consider each component but to group components that are similar regarding the expected downtime cost. This might be an interesting starting point for further research.

The condition monitoring data and the empirical data are not processed and analyzed within the presented procedure. Only the resulting probabilities are considered within the model. Therefore, the reliability of the probabilities based on this data cannot be ensured but is decisive for the quality of the resulting optimum number of spare parts. Expanding the procedure with a sub-model in which probabilities are determined out of e.g., sensor data, would therefore be a helpful approach. The presented procedure to determine the optimum number of spare parts provides the basis for further development and refinery. Additionally, further business models can be developed, especially business models that concretely combine spare parts optimization and further predictive maintenance approaches.

5 Overall Discussion, Implications and Limitations

Smart services are a relatively new research field, rising with the possibilities of the digital transformation and the IoT (Dreyer et al. 2019b). Starting with the first publication in the field of smart services in 2003 (i.e. Zo 2003), the number of publications that went in the same direction rose significantly. This indicates that smart services and new business models enabled by the digital transformation are a topical subject in IS research. The rapid development has impact on scientific research. A systematic literature review according to Webster and Watson (2002) formed the basis of the following answers of the research questions. Thereby, it was searched through different databases using predefined search terms. The objective was to identify many publications that deal with smart services. Because of the fact that the number of publications is continually increasing, the literature review reflects the current state of research. Although this is true for all literature reviews, in the field of smart services the state of research is changing rapidly. This limitation leads to the necessity to see the answers of the research questions in the context of the time.

In addition to academic aspects, the opportunities through the digital transformation have significant influence on the market. Established companies in the manufacturing industry do not anymore only sell physical products but combine them with individual services (Neff et al. 2013, Oliva and Kallenberg 2003, Schrödl and Bensch 2013) or even offer services solely (Haider 2011). This shift in emphasis provides the opportunity for companies to gain competitive advantages because new revenue streams are created (Tukker and Tischner 2006). Additionally, individual, continuously changing customer requirements can be satisfied through analyzing condition monitoring data (Lê Tuán et al. 2012). This leads to increased customer loyalty (Barrett et al. 2015). To reach this, the customer must be continually in focus (Dreyer et al. 2019b). When designing a smart service and developing a suitable business model, the customer's perspective must be taken. This importance is undisputed in the literature. Nevertheless, it is not reflected in current smart service research. Technical aspects and the importance of data are primarily considered. Such aspects can better be investigated theoretically because their potential and possibilities are similar for further applications apart from smart services. A challenge is that there are not yet best practice approaches for smart services and business models related to the digital transformation (Dreyer et al. 2019b). But knowledge about potential customer behavior, customer needs and their environment can only be gained through use cases and practical applications. In turn, the knowledge can be used for further research and to better understand smart service theory. This helps both researchers and practitioners.

Coming from the individual customer, the market as a whole must also be considered (Dreyer et al. 2018b). For smart service providers and those who want to realize a new business model, it is necessary to understand the market. A comprehensive market analysis is required before introducing a smart service. For operating smart services, the market and its potential changes should also be kept in mind. A study showed that experts highly recommend considering the market although this is not made a subject of discussion in IS research (Dreyer et al. 2018b). On the one hand, the target group must be identified (Osterwalder and Pigneur 2010). The strategy behind the new business model must correspond to the needs of the target group. Aspects such as revenue channels, the pricing strategy as well as security and privacy concerns must be part of the business model strategy (Gretzel et al. 2015, Kennedy and Keskin 2016, Osterwalder and Pigneur 2010). Thereby, the culture in which a new smart service should be introduced must be considered (Dreyer et al. 2018b). Depending on the culture, the best market entry differs. For example, the openness towards innovative products and services differs across countries. An aspect that results from this is that marketing activities must be adjusted according to the cultural background. On the other hand, a comprehensive competitor analysis is necessary for successful smart services. Only when potential competitors and the size of the market are known, a reliable assessment is possible regarding the chances of success. This is especially a challenge for smart services because often they operate worldwide (Dreyer et al. 2018b). This complicates both the analysis of the market and of the competitors. Worldwide analysis can be time consuming and expensive. Approaches for overcoming this challenge were not considered within this dissertation. For most of the research questions a demand for smart services and innovative business models was implied.

The way how smart services are designed is highly diverse (Beverungen et al. 2017b). On the one hand, smart services can be provided for many different applications in many different branches and for different types of customers. On the other hand, every smart service is adapted to specific conditions, requirements and the environment (Dreyer et al. 2019b, Kynsilehto and Olsson 2011). This means that the same smart service is carried out in different ways for the customers because of its customization. For example, an important aspect is infrastructure conditions. Depending on the infrastructure, the most suitable information architecture must be developed. Although design principles for an information architecture were developed in the Chapters 3.1 and 3.2, an adaption to the specific context is necessary. Thereby, the existing infrastructure is an aspect that must be considered. Another important aspect is the smart service for which the information architecture should serve (Dillon and Turnbull 2005). Considering the manufacturing industry, the smart service determines the structure of the digital twin. The digital twin contains all relevant data and information of a machine and its components (Rosen et al. 2015). But the relevance depends on the purpose for which the smart service serves. It must be investigated in detail which data should be collected and in which frequency. Additionally, the analyses that are carried out and their time frames must be determined. Thereby, it must be considered that this must not be investigated once but continually adapted if necessary. The same applies to the knowledge management system. The design and structure differs, depending on the smart service and its requirements (Dreyer et al. 2019a). As in the case of the digital twin, the knowledge management system is not static but dynamic. This means that knowledge is continuously corrected, maintained and added (Ferneley et al. 2002). The design of digital twins and knowledge management systems were presented in a general way to provide an overview of the topics (Dreyer et al. 2019a, Olivotti et al. 2019). Concrete guidelines how to realize them did not form part of the dissertation. This was because it was mainly focused on the design of smart services and their underlying business models. Nevertheless, the implementation of digital twins and a suitable knowledge management system must not be neglected when planning smart services.

When designing and planning smart services and new business models strategically, technical aspects must be considered. A useful strategy of innovative business models requires that it is technically feasible. Thereby, the question arises as to what follows what. One could argue that the technical possibilities, in the case of smart services these are the possibilities through the digital transformation, should be the starting point for investigating new services and business models. All kinds of smart services can be imagined but the feasibility depends on technical options. From this perspective, systematic analyses of the current state of technology and its possibilities must be examined before strategic planning and design begins. The other approach is that the technical implementation must follow strategic decisions. Thereby, new service ideas are developed regardless of what might be technically possible. After identifying and strategically describing the smart service, the technical solution must follow. Thereby, there is the possibility that the realization is unsuccessful. The preferred option depends on circumstances. Developing technical solutions according to the strategic design of a smart service can be time-consuming and cost-intensive. But thinking about novel services and business models in the first step might lead to higher innovativeness, at least in the long term.

Within this dissertation, it was emphasized that all lifecycle phases of a smart services must be considered, not isolated but in connection with each other. In most of the research questions the first two phases, namely smart service strategy and smart service design, of in total five phases were considered. The later phases move away from strategic decisions and concretize the smart services. The first two phases can be seen as the foundation for successful implementation and operation. Nevertheless, the other three phases are also highly important to investigate in order to receive a comprehensive picture of smart services and their business models.

Not only strategic and technical aspects must be considered together. Also academic research and practical relevance must be both ensured (Iivari 2007, Lindgren et al. 2004, Sein et al. 2011). This is especially important for topics related to the digital transformation because these topics are highly relevant in practice (Issa et al. 2018). Within the dissertation, practical problems and challenges were systematically investigated following academic standards. This contributes both to theory and practice. The research project InnoServPro was used as background for answering some of the research questions. On the one hand, it was ensured that the research questions consider real problems from the field. Organizational problems were taken as starting points for investigations. The use of established research designs contributed to academic rigor while practical challenges were handled. The findings help researchers to better understand how smart services work. Practitioners can use academic elaborations to work out new business models as well as implement and continually improve smart services. On the other hand, the research project enabled to work together with experts from the field. Practical experiences, e.g., regarding customer’s requirements and market trends, helped to answer research questions combining different perspectives. An advantage of working and researching within a research project is that experts from different companies are brought together. For academic research, practical relevance is ensured through a continuous exchange. Furthermore, in contrast to single use cases where only one company is considered, within a research project it is benefitted from multiple viewpoints and experiences. Another advantage is that a prototype in form of a demonstration machine, developed during the project, could be used to validate research results and making applicability checks (Olivotti et al. 2019). The information architecture that was developed in Chapter 3 was applied to the demonstration machine. Thereby, it was shown that the architecture is not only a theoretical construct but also useful in practice. The research project enabled to bring together theoretical and strategic ideas with practical realization. This is both advantageous for the research project and the quality of academic research. Nevertheless, it must be considered that the number of companies that worked in the research project is not necessarily representative. It must be taken into account that all companies that work in such research projects are highly interested in new developments and innovative ideas. Therefore, some assumptions that were made are not necessarily true for other companies in the manufacturing industry.

6 Overall Conclusions and Outlook

Smart services and innovative business models resulting from the digital transformation pave the way for new revenue streams and high customer loyalty (Barrett et al. 2015, Tukker and Tischner 2006). Both smart services and new business models are not only a theoretical topic but also highly relevant in practice. In total, nine research questions contribute to a better understanding of that topic in theory and practice. The design of smart services and their underlying business models is manifold. Mainly focusing the manufacturing industry, the elaborations show the diverse possibilities of new service approaches in that field.

The investigations according to the research questions were divided into three chapters. In the first chapter of the main part it was looked on smart services and new business models from a general perspective. A comprehensive literature review revealed the current state of research and provided approaches for further research (Dreyer et al. 2019b). Among other things, it turned out that the importance of the customer is underestimated in academic elaborations. In the manufacturing industry, availability of components, machines and production lines is one of the most requested demands (Haider 2011, Mert et al. 2016). Therefore, many business models for the manufacturing industry consider the guarantee of availability. This is reflected by answering the research question of how to apply availability-oriented business models in practice (Olivotti et al. 2018a). The role of knowledge management is pointed out as reliable knowledge management is essential for successful smart services (Dreyer et al. 2019a). There is not the only one best design of a knowledge management system for all types of smart services but the best structure differs. A reference model exemplifies the diversity of knowledge management designs. Independent from the specific smart service, there are success factors that should be considered when introducing a new smart service (Dreyer et al. 2018b). Especially the market and the customers with their environment must be considered. This is partially neglected in theoretical investigations.

After introducing smart services and innovative business models in the first chapter of the main part, it is focused on the manufacturing industry. Most of the smart services and new business models that arise in the manufacturing industry are based on a reliable installed base management (Dreyer et al. 2017). The key requirement concerns high machine availability (Haider 2011, Mert et al. 2016). Machine operators are interested in getting rid of the risk of a machine failure and production downtime. But to be able to provide services that guarantee a certain level of availability, the machines and their conditions must be known very well. Therefore, an installed base management is necessary, containing all relevant data and information related to the machines and their components. Design principles for an information architecture for installed base management was presented (Dreyer et al. 2017). Initially, the information architecture was theoretically developed. Different sources and interfaces to external systems were considered. Additionally, the value network idea was integrated in the architecture. The practical application of the information architecture in a use case demonstrated its benefits for creating digital twins (Olivotti et al. 2019).

A main application field of digital twins is predictive maintenance, considered in the third chapter of the main part. Reliable maintenance planning contributes to low downtimes, both planned and unplanned (Bouvard et al. 2011). The design of predictive maintenance offers is diverse but follows similar patterns. This is reflected in a taxonomy that classifies existing predictive maintenance business models (Passlick et al. 2019). Seven different dimensions were examined through which six archetypes were identified. Talking about predictive maintenance, a balance between costs and default risk has always to be found (Olivotti et al. 2018b). The risk of a machine downtime can be determined through using sensor data. In the case of planning maintenance activities for multiple machines in several periods, the costs consist of fixed maintenance costs per maintenance operation in a production line and individual maintenance costs of the different machines. A developed decision support system helps to group maintenance activities, considering costs, probabilities of default and further variables (Olivotti et al. 2018b). Focusing the optimization of spare parts inventory, the costs that must be balanced with default risks of the machines are the provision costs of the spare parts. A novel business model approach is presented that enables to adapt the number of spare parts in each period (Dreyer et al. 2018a). In connection with a mathematical optimization model and an algorithm, the approach shows in a concrete example how the digital transformation enables new services and underlying business models.

The digital transformation and the resulting possibilities for innovative smart services and business models is a relatively recent development. This has impact both on theory and practice. There are several topics that are not yet investigated or not sufficiently investigated. For example, the possibilities that arise through the use of machine learning technologies for smart services are almost completely neglected (Dreyer et al. 2019b). The chances and challenges that result from operating in value networks are only partially considered when investigating smart services and new business models. On the one hand, there are many research gaps (Dreyer et al. 2019b). Closing these gaps would contribute to a better understanding of the topic and enables to better estimate possibilities, challenges and trends. On the other hand, there are not yet best practice approaches (Dreyer et al. 2019b). Therefore, there are no guidelines for practitioners that have finally proved to be helpful. In the future, there should be a constant further development. This progress highly depends on the development of the digital transformation. Research results that were worked out at a certain point in time should be considered in future contexts, taking novel knowledge into account. Therefore, both for researchers and practitioners it is necessary to constantly update current research results, including new findings from novel publications and practical experiences.

In the private sector, many different smart services and new business models are practically realized (Ali et al. 2017). Applications such as smart home functionalities are already offered on the market. In the industrial sector, the development according to the digital transformation is often slower (Issa et al. 2018). Possible reasons are regulations and the organizational structures of companies. Although there are many companies that are recently founded with the objective of providing or using smart services, there are many companies in the manufacturing industry that exist for decades. Their structures and regulations are often not compatible with new developments and therefore they are adapting themselves slowly (Issa et al. 2018). For further research, investigating approaches for reorganizing structures would help to overcome those problems. Investigations in what sense findings and applications from the private sector can be applied to the manufacturing industry would help to forward research in the manufacturing environment. For further research, the digital transformation and its meaning and possibilities for the manufacturing industry should not be considered in isolation but in connection with other sectors. Learning from each other and gaining new, universal knowledge about innovative business models and smart services helps drawing the bigger picture referring to the digital transformation. Additionally, not only other sectors and its ways to design smart services and business models should be considered but also technical aspects. Smart services cannot be designed without looking at technical opportunities (Spottke et al. 2016). For further research, interdependencies between strategic design and technical development should be considered consequently to ensure applicability in practice.

The dissertation contributes both to theory and practice in the fields of smart services and innovative business models enabled through the digital transformation. Academic rigor is ensured through using different research designs that are widely accepted in IS research. Comprehensive and systematic literature reviews contribute to a solid theoretical foundation. Practical relevance is given through taking practical problems as starting points for investigations. The collaboration within a research project, the performance of expert interviews as well as focus group discussions ensured a constant exchange between researchers and practitioners. The dissertation provides a comprehensive overview of smart services and corresponding business models. In addition to general aspects such as the current state of research in the field of smart services, insights in different aspect concerning the manufacturing industry were provided. The dissertation contributes to a better understanding of smart services and new business models both in theory and practice and emphasizes their importance. The dissertation is a suitable starting point for further investigations in the topical subject of smart services and innovative business models enabled through the digital transformation.

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Appendices

Appendix A1

Towards a Smart Services Enabling Information Architecture for Installed Base Management in Manufacturing

Sonja Dreyer, Daniel Olivotti, Benedikt Lebek and Michael H. Breitner

In: Proceedings of the 13th International Conference on Wirtschaftsinformatik, pp. 31–45

Link: https://aisel.aisnet.org/wi2017/track01/paper/3/

Abstract:

In the manufacturing industry the provision of smart services is an opportunity to gain a competitive advantage. As there are high demands on machine availability, smart services in the field of installed base management are important. Through integrating condition monitoring data with installed base data a digital twin of the installed base can be created. This enables comprehensive analyses and the provision of individualized smart services. But this requires to structure and standardize the data. Following the action design research (ADR) approach, in this article design principles of an information architecture are developed. The architecture is evaluated and improved in the context of an international engineering and manufacturing company. A test run with real machine data shows the applicability in practice.

Appendix A2

Optimizing Machine Spare Parts Inventory Using Condition Monitoring Data

Sonja Dreyer, Jens Passlick, Daniel Olivotti, Benedikt Lebek and Michael H. Breitner

In: Operations Research Proceedings 2016, pp. 459–465

Link: https://link.springer.com/chapter/10.1007/978-3-319-55702-1_61

Abstract:

In the manufacturing industry, storing spare parts means capital commitment. The optimization of spare parts inventory is a real issue in the field and a precise forecast of the necessary spare parts is a major challenge. The complexity of determining the optimal number of spare parts increases when using the same type of component in different machines. To find the optimal number of spare parts, the right balance between provision costs and risk of machine downtimes has to be found. Several factors are influencing the optimum quantity of stored spare parts including the failure probability, provision costs and the number of installed components. Therefore, an optimization model addressing these requirements is developed. Determining the failure probability of a component or an entire machine is a key aspect when optimizing the spare parts inventory. Condition monitoring leads to a better assessment of the components failure probability. This results in a more precise forecast of the optimum spare parts inventory according to the actual condition of the respective component. Therefore, data from condition monitoring processes are considered when determining the optimal number of spare parts.

Appendix A3

Maintenance Planning Using Condition Monitoring Data

Daniel Olivotti, Jens Passlick, Sonja Dreyer, Benedikt Lebek and Michael H. Breitner

In: Operations Research Proceedings 2017, pp. 543–548

Link: https://link.springer.com/chapter/10.1007/978-3-319-89920-6_72

Abstract:

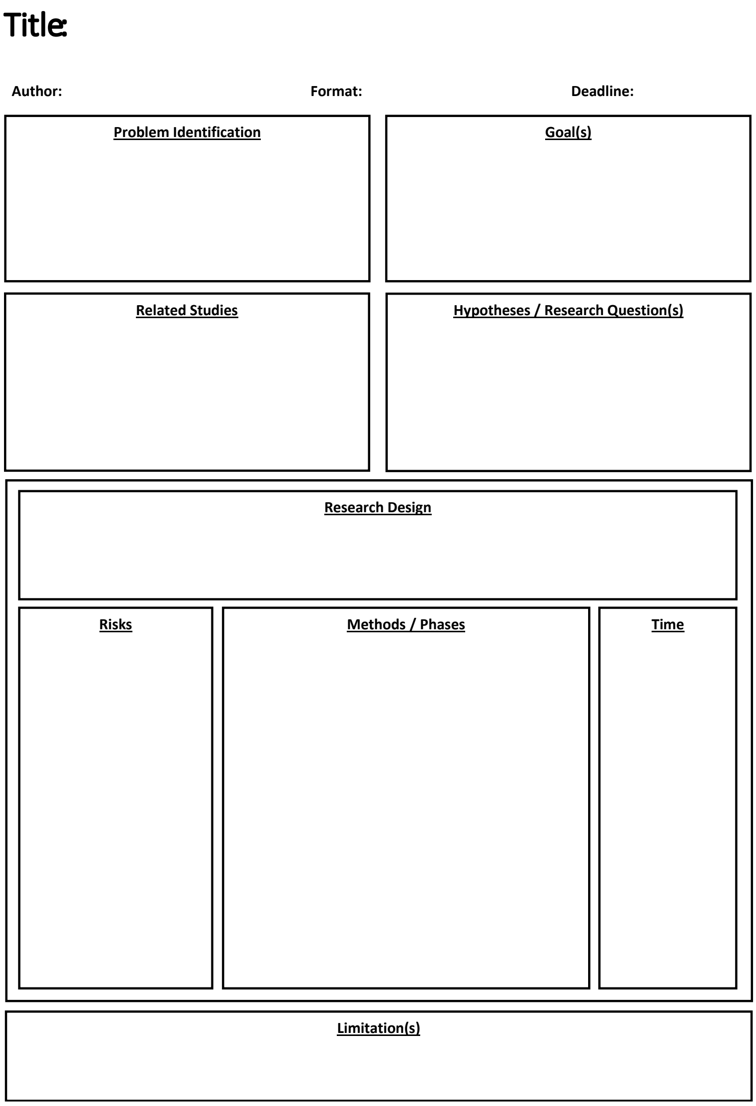
Maintenance activities of machines in the manufacturing industry are essential for keeping machine availability as high as possible. A breakdown of a single machine can lead to a complete production stop. Maintenance is traditionally performed by predefined maintenance specifications of the machine manufacturers. With the help of condition-based maintenance, maintenance intervals can be optimized due to detailed knowledge through sensor data. This results in an adapted maintenance schedule where machines are grouped to reduce set up and fixed maintenance costs. Apart from time savings, this also reduces costs. A decision support system with optimization model for maintenance planning is developed considering the right balance between the probabilities of failure of the machines and the potential breakdown costs. The current conditions of the machines are used to forecast the necessary maintenance activities for several periods. The decision support system helps maintenance planners to choose their decision-making horizon flexibly.

Appendix A4

Assessing Research Projects: A Framework

Jens Passlick, Sonja Dreyer, Daniel Olivotti, Benedikt Lebek and Michael H. Breitner

In: IWI Discussion Paper Series, paper 83



Appendix A5

Critical Success Factors for Introducing Smart Services: A Supplier's Perspective

Sonja Dreyer, Jan Zeren, Benedikt Lebek and Michael H. Breitner

In: Proceedings of the Multikonferenz Wirtschaftsinformatik 2018, pp. 410–421

Link: http://mkwi2018.leuphana.de/programm/sessions/#8

Abstract:

Smart services enable providers to win new customers and to strengthen the relations with existing ones. Established companies emphasize the importance of providing smart services in addition to their current portfolio. To be able to offer smart services successfully, various preconditions must be fulfilled. Critical success factors are identified that can be used for companies which want to offer smart services in the future, focusing potential customers and their needs. Implementing smart services in existing business environments to offer added value to customers is a challenge. Due to a systematic literature review, critical success factors for introducing smart services are extracted from academic literature with the objective of an introduction in the interests of customers. Experts from practice evaluated and complemented the success factors. Both a theoretical and a practical perspective is taken to support introducing smart services.

Appendix A6

Realizing Availability-Oriented Business Models in the Capital Goods Industry

Daniel Olivotti, Sonja Dreyer, Patrick Kölsch, Christoph. F. Herder, Michael H. Breitner and Jan C. Aurich

In: Procedia CIRP, vol. 73, pp. 297–303

Link: https://www.sciencedirect.com/science/article/pii/S2212827118304803

Abstract:

The validation results of a concept for the development of availability-oriented business models are addressed. The developed concept contains five steps by means of primarily design thinking methods. For the validation, the developed concept is applied at Lenze, a German innovative manufacturer of drive and automation solutions for materials handling, handling technology, packaging industry, robotics and automotive industry. Therefore, a use case is defined, business models, extended value networks, persona analyses and customer journey are elaborated. The results show the applicability of the concept for the development of availability-oriented business models for the capital goods industry.

Appendix A7

Modeling Framework for Integrated, Model-Based Development of Product-Service Systems

Hristo Apostolov, Matthias Fischer, Daniel Olivotti, Sonja Dreyer, Michael H. Breitner and Martin Eigner

In: Procedia CIRP, vol. 73, pp. 9–14

Link: https://www.sciencedirect.com/science/article/pii/S2212827118304888

Abstract:

Product-service systems (PSS) are seen as the 21st-century solution for direct delivery of value to customers under the requirements of high availability, quality, and reduced risks. With mutual benefits for customers, manufacturers, service providers and often the environment, PSS represent a promising approach to sustainable development. This paper addresses the integrated development of product-service systems consisting of physical products/systems and services and proposes an integrated modeling framework that utilizes the Systems Modeling Language (SysML). A use case from Lenze, a German automation company, demonstrates applicability of the integrated modeling framework in practice.

Appendix A8

Creating the Foundation for Digital Twins in the Manufacturing Industry: An Integrated Installed Base Management System

Daniel Olivotti, Sonja Dreyer, Benedikt Lebek and Michael H. Breitner

In: Information Systems and e-Business Management, vol. 17, issue 1, pp. 89–116

Link: https://link.springer.com/article/10.1007/s10257-018-0376-0

Abstract:

Services play an important role in the manufacturing industry. A shift in emphasis from selling physical products to offering product–service systems is perceived. Detailed knowledge of machines, components and subcomponents in whole plants must be provided. Installed base management contributes to this and enables services in manufacturing to maintain high machine availability and reduce downtimes. Installed base management assists in data structuring and management. By combining installed base data with sensor data, a digital twin of the installed base results. Following the action design research approach, an integrated installed base management system for manufacturing is presented and implemented in practice. An engineering and manufacturing company is involved in the research process and ensures practical relevance. Requirements are not only deduced from the literature but also identified in focus group discussions. A detailed test run with real data is performed for evaluation purpose using a demonstration machine. To enable a generalization, design principles for the development and implementation of such an integrated installed base management system are created.

Appendix A9

Focusing the Customer through Smart Services: A Literature Review

Sonja Dreyer, Daniel Olivotti, Benedikt Lebek and Michael H. Breitner

In: Electronic Markets, vol. 29, issue 1, pp. 55–78

Link: https://link.springer.com/article/10.1007/s12525-019-00328-z

Abstract:

Smart services serve customers and their individual, continuously changing needs; information and communications technology enables such services. The interactions between customers and service providers form the basis for co-created value. A growing interest in smart services has been reported in the literature in recent years. However, a categorization of the literature and relevant research fields is still missing. This article presents a structured literature search in which 109 relevant publications were identified. The publications are clustered in 13 topics and across five phases of the lifecycle of a smart service. The status quo is analyzed, and a heat map is created that graphically shows the research intensity in various dimensions. The results show that there is diverse knowledge related to the various topics associated with smart services. One finding suggests that economic aspects such as new business models or pricing strategies are rarely considered in the literature. Additionally, the customer plays a minor role in IS publications. Machine learning and knowledge management are identified as promising fields that should be the focus of further research and practical applications. Concrete ideas for future research are presented and discussed and will contribute to academic knowledge. Addressing the identified research gaps can help practitioners successfully provide smart services.

Appendix A10

Kritische Erfolgsfaktoren für die Einführung von Smart Services: Eine Anbietersicht

Sonja Dreyer, Jan Zeren, Benedikt Lebek and Michael H. Breitner

In: Robra-Bissantz S., Lattemann C. (eds.) Digital customer experience, pp. 25–38. Part of the Edition HMD book series (EHMD)

Link: https://link.springer.com/chapter/10.1007/978-3-658-22542-1_2

Abstract:

Smart Services ermöglichen es Anbietern, neue Kunden zu gewinnen und die Beziehungen zu bestehenden Kunden zu stärken. Etablierte Unternehmen erkennen, dass neben ihrem derzeitigen Portfolio auch intelligente Dienstleistungen angeboten werden sollten, um am Markt bestehen zu können. Um Smart Services erfolgreich anbieten zu können, müssen verschiedene Voraussetzungen erfüllt sein. Es werden kritische Erfolgsfaktoren identifiziert, die von Unternehmen genutzt werden können, die in Zukunft intelligente Dienstleistungen anbieten und potenzielle Kunden und deren Bedürfnisse fokussieren wollen. Die Implementierung von Smart Services in bestehenden Geschäftsumgebungen, mit dem Ziel, den Kunden einen Mehrwert zu bieten, ist eine Herausforderung. Mittels einer systematischen Literaturrecherche werden kritische Erfolgsfaktoren für die Einführung von Smart Services aus der wissenschaftlichen Literatur extrahiert, mit dem Ziel einer Einführung im Interesse der Kunden. Experten aus der Praxis bewerteten und ergänzten die Erfolgsfaktoren. Sowohl eine theoretische als auch eine praktische Perspektive werden eingenommen.

Appendix A11

Predictive Maintenance as an Internet of Things Enabled Business Model: Towards a Taxonomy

Jens Passlick, Sonja Dreyer, Daniel Olivotti, Lukas Grützner, Dennis Eilers and Michael H. Breitner

Submitted

Abstract:

Predictive maintenance (PdM) as an important application of the Internet of things (IoT) is discussed in many companies, especially in the manufacturing industry. PdM uses data, usually sensor data, to optimize maintenance activities. This study develops a taxonomy for the classification of PdM business models. The taxonomy enables a comparison and analysis of PdM business models. Business models of 113 companies are described with the developed taxonomy. With a cluster analysis six archetypes are identified and discussed. The three archetypes hardware development, analytics provider, and all-in-one are most frequently represented in the data set. For the analysis of the clusters, a new visualization procedure is used which consists of an autoencoder application. The analysis enables practitioners to discuss their own business models and those of other companies. The implication that an IoT architecture is an influential differentiator for PdM business models is important for further research.

Introduction

The introduction of the Internet of things (IoT) is currently the subject of intense discussion both in practice and scientifically (Whitmore et al. 2015). Not only the private but also the industrial environment that is changing through the IoT is discussed. The term industrial internet of things (IIoT) is also used here. Predictive maintenance (PdM) is one way of using the IIoT to create value. PdM means using data, especially sensor data of IoT devices, to optimize maintenance activities. Often this also includes the term "Condition Monitoring". The aim of PdM is not to carry out maintenance unnecessarily early, but also not too late. This includes being able to make forecasts about the further deterioration of e.g., a machine. Especially unscheduled deterioration can also be detected to proactively take action.

The consulting firm PricewaterhouseCoopers, in cooperation with Mainnovation, came to the conclusion that out of 280 surveyed companies from Germany, Belgium and the Netherlands, 132 companies might want to implement a PdM solution and 52 companies are already working on such an implementation (PricewaterhouseCoopers 2017). This shows the relevance for companies. The relevance of PdM is also increasing in the scientific field (Daily & Peterson 2017). However, it is difficult for companies to get an overview of the market situation of PdM offers. Which providers are on the market and what do they offer? Previous research in the IoT environment has already shown that understanding the business models of company partners is important for long-term success (Dijkman et al. 2015). Also for a scientific discussion of PdM business models, it is important to get an overview of different forms of PdM business models to better understand how PdM business models work in practice. Companies can better locate their own business models on the market and identify potential growth opportunities. This results in the following research question (RQ), which we address in our research:

RQ: Which elements of PdM business models are important and which characteristics are interrelated on the market?

The article proceed as follows: First we will describe how we define a PdM business model. Based on this, we develop a taxonomy for PdM business models using a procedure according to Nickerson et al. (2013). We then use the final taxonomy to classify the business models of 113 companies. Based on this classification, we conduct a cluster analysis and build archetypes that represent typical PdM business models. The results are analyzed and discussed. Further, implications and limitations are outlined and further research is suggested.

Predictive Maintenance and Related Literature

A comprehensive insight into the current condition of a component or machine is necessary for PdM (Sipos et al. 2014). More abstract, the key for PdM is data (Borgi et al. 2017). Usually, a central server is used to collect, transmit and process the data (Wang et al. 2017). Monitoring and determining the current state of equipment is the first step of PdM (Hui et al. 2008). The beginning of degradation must be detected as early as possible (Borgi et al. 2017, Khazraei and Deuse 2011). It must be possible to extract all information that is necessary for reliable PdM. Sensors are a source for condition-related data (Sipos et al. 2014). As data collection in (near) real-time is necessary, control tools can be used that are capable of collecting data automatically from several components and systems (Aivaliotis et al. 2017). Data do not only have to be collected but also must be analyzed (Cachada et al. 2018). Tools for data analysis do not only process sensor data but also take the maintenance history, operational data, design and application into account (Darwanto et al. 2012). Indicators must be identified, measured and modelled so that activities can be derived from that (Groba et al. 2007). Vibration analysis, thermal images (Barbera et al. 1996), trend analysis and simulation (Aivaliotis et al. 2017) are exemplary techniques that are used. The described elements are summarized in general IoT architectures (e.g., Chen 2013, Turber et al. 2014).

The fact that system's downtimes are minimized through PdM leads to a reduction of production losses (Baidya and Ghosh 2015, Spendla et al. 2017, Zoll et al. 2018). In contrast to regularly performed maintenance activities, PdM takes the current condition of the system into account (Chu et al. 1998). This leads to a reduction of maintenance activities (Last et al. 2010, Susto et al. 2013). Maintenance activities are performed as late as possible, under the condition that the system is still running in its intended way (Mattes and Scheibelhofer 2012). The probability of extensive failures is reduced (Darwanto et al. 2012). From an economic perspective, costs are reduced because of less and precise maintenance activities as well as lower probabilities of default (Wang et al. 2009). Additionally, the customer experience is increased and the customer loyalty is strengthened (Gerloff and Cleophas 2017).

In the literature, maintenance activities are often classified, mostly regarding their intervention point. It reflects that the definition of PdM is not standardized. Önel et al. (2009) say that there are not more than two types of maintenance: breakdown and preventive maintenance. Richter et al. (2017) differentiate between reactive, predictive and proactive maintenance activities. Thereby, predictive does only mean that warnings are displayed, without subsequent action. Susto et al. (2012) see PdM as the highest expansion of maintenance activities. The first step is reactive maintenance, followed by preventive and condition based maintenance. Condition-based maintenance is different from PdM because only the current condition is the basis for decisions. In contrast, prediction tools and methods are used in PdM (Susto et al. 2012). In another article condition-based maintenance and PdM are equated (Last et al. 2010). Another point of view describes PdM as the aggregation of condition-based and prognostic-based maintenance (Araiza 2004). Mustakerov and Borissova (2013) name condition-based maintenance the highest expansion that combines preventive and PdM with real-time monitoring. The other way round, Groba et al. (2007) argue that PdM is based on the concept of condition monitoring. The presentation of You (2017) goes in the same direction. Further, the author sees a temporal development from reactive maintenance over condition-based monitoring to PdM. Khazraei and Deuse (2011) mention avoidance-based, condition-based, and detective-based maintenance as tactics within PdM. The definition of PdM is therefore different in the details. In the present article, we define PdM as the most comprehensive form of maintenance that includes condition-based maintenance and further types of maintenance that are enabled by data analysis.

Although there are many articles dealing with PdM there is not yet a comprehensive taxonomy available. A taxonomy enables a better understanding of PdM business models as one concrete example of an IoT use case. The individual elements of the business models can be identified and their relations examined (Glass & Vessey 1995). Taxonomies have already been developed in related topics. Hartmann et al. (2016) develop a taxonomy for startups of data-driven business models, Täuscher and Laudien (2018) examine platform business models and two different FinTech startup taxonomies are provided by Gimpel et al. (2017) and Eickhoff et al. (2017). Different maintenance strategies are already classified but not as detailed as it is possible within a taxonomy. A taxonomy shows how diverse PdM offers are by considering existing offers from companies all over the world.

Taxonomy Development

Procedure

In developing our taxonomy, we have oriented on Nickerson et al. (2013). The term “taxonomy” is defined as “a set of it n dimensions Di (i=1, ..., n) each consisting of ki (ki>2) mutually exclusive and collectively exhaustive characteristics […].” (Nickerson et al. 2013, p. 340). Starting from the analysis of scientific literature on business models, the dimensions of the taxonomy are derived conceptually. Subsequently, related characteristics are developed by empirically examining a large number of globally distributed companies active in PdM. During the development of the taxonomy, the focus is usually on a certain area of interest, which is determined as a meta characteristic at the beginning of the process. This meta characteristic is a superordinate and abstract description of the area on which the taxonomy focuses, and serves as the basis for the choice of dimensions and characteristics in the taxonomy. In our case, the meta characteristic is to define elements of PdM business models. The taxonomy development takes place in several iterations (Nickerson et al. 2013). In each iteration a different approach is conceivable. Either the taxonomy is adapted based on concepts (conceptual-to-empirical), usually existing models, or on empirical data (empirical-to-conceptual). Figure 1 shows this procedure. The characteristics assigned to a company, according to the definition of Nickerson et al. (2013), can be seen as exclusive. Exclusive means that in each dimension exactly one characteristic is assigned to a company. After each iteration, a decision is made on the basis of various end conditions whether a further iteration is necessary. The end conditions used were adapted from Nickerson et al. (2013) (see Appendix, Table 5). The following section describes the steps performed in each iteration.

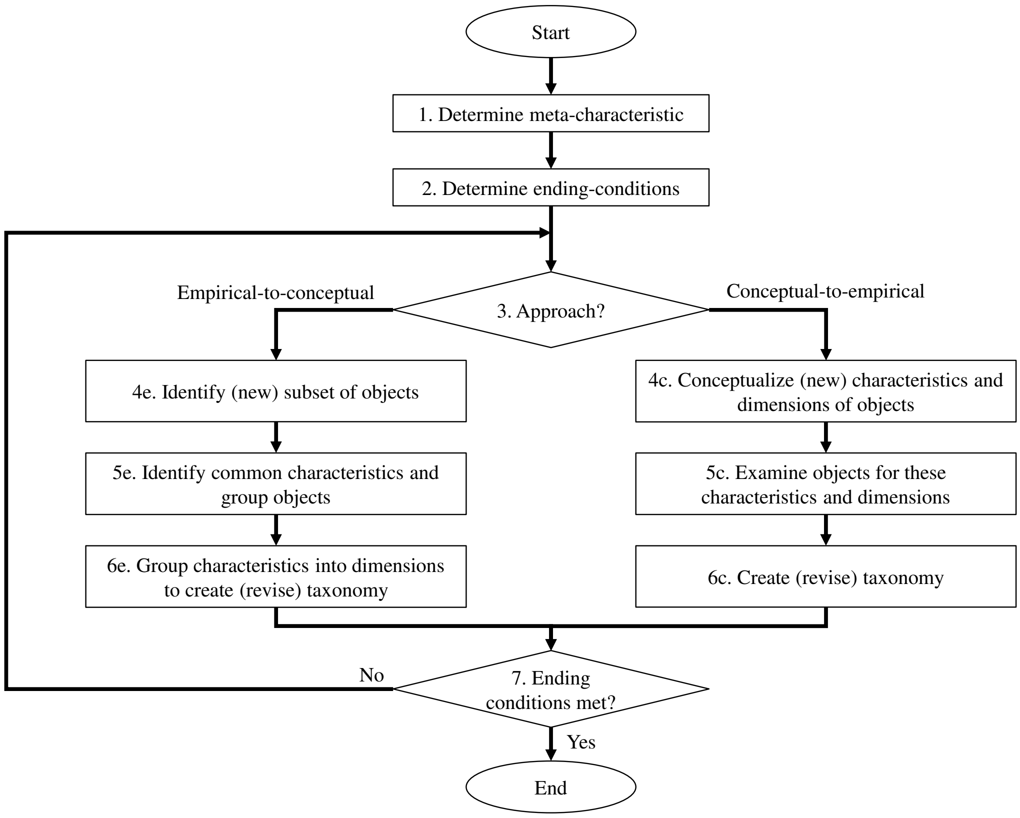


Figure 1 Taxonomy development procedure by Nickerson et al. (2013)

Iterations

In the first iteration, the approach was conceptual-to-empirical. Based on the analysis of literature on business models, existing knowledge was reviewed and key terms relevant to our taxonomy were identified. We compared electronic business model elements by Afuah and Tucci (2001), Alt and Zimmermann (2001), Brousseau and Penard (2007), Mahadevan (2000), Osterwalder and Pigneur (2010). The Business Model Canvas by Osterwalder and Pigneur (2010) summarizes the majority of the elements of business models in the literature. Additionally, the Business Model Canvas is highly regarded in practice. Therefore, it forms the basis for our taxonomy. Possible dimensions were discarded in which many PdM business models are similar (e.g., key resources) and dimensions where no relevant information is available (cost structures, key partners). According to Osterwalder and Pigneur (2010), the element sales channels is about which methods are used to sell a product or service and how customers are reached. These include, for example, the use of Internet marketplaces or the direct use of sellers. Further, revenue streams was included to answer the question which payment models are offered to customers. Pay users once for a complete product or a monthly use fee for a specific service? To describe the type of customers, the dimension customer segment was also included. At the end of the first iteration this resulted in the following dimensions: key activities, value proposition, revenue streams, sales channel, and customer segment. Several end conditions of the taxonomy development were not fulfilled after the first iteration (see Appendix, Table 5), therefore a further iteration was necessary.

In the second iteration, the approach was empirical-to-conceptual and data from real PdM business models were analyzed. To this purpose, we conducted 42 interviews with representatives of various companies at the "Hannover Industrie Messe" 2018, a leading fair for industrial automation and IT technologies. We have discussed different topics on various aspects of the company (can be found in the appendix). The survey was prepared on the basis of the previously discussed knowledge about business models and the results of the first iteration of the taxonomy development. The length of the interviews was between five minutes and 40 minutes, on average about 15 minutes. In addition, Google was used to search for PdM companies using search terms including "Companies", "Predictive Maintenance" and "Condition Monitoring". Webpages with lists of companies which have PdM business models were found there. This resulted in a database of 71 companies after conducting the interviews and the Google search. We then used the Crunchbase website (a database containing various information about companies, started to track start-ups) to search for appropriate companies. Further, we used a Crunchbase base account to download the open data map. In the file, containing information about the companies, the terms "predictive maintenance" and "condition monitoring" were used for a search in the short descriptions. Thereby, 42 additional companies were identified, which resulted in 113 companies in our entire database (can be seen in the Appendix, Table 7).

Initially, a random sample of ten companies was examined from which suitable characteristics for the dimensions obtained in the first iteration were derived. Similar characteristics were summarized to a single characteristic. For example, chemical, food, automotive, steel, and others were combined in the *manufacturing industry* characteristic. The production of various hardware components from the fields of sensor technology, electronics, networking, and machines was combined to *hardware development*. Data analysis and the digital representation of this data were combined to *condition monitoring*. In addition, during this empirical iteration, it was found that the taxonomy requires a further dimension called *clients*, which complements important characteristics missing in the dimension *customer segment*. It turned out that IoT respectively PdM business models can be differentiated according to the customers to be addressed by the company. For example, some companies have customers who again sell to other companies (*B2B2B*). Further, it was recognized that another differentiation characteristic is the technical layer to which a company refers with its offer. This refers to the layers as described by IoT architecture models (e.g., Chen 2013, Turber et al. 2014). The models usually consist of four levels from the recording to the analysis of the data. Such models are used to describe the different prerequisites that are necessary for machine to machine communication. In the business model context it allows conclusions on which layer a company offers a solution. The end conditions of the taxonomy were not reached due to the newly identified dimensions and characteristics. Furthermore, the taxonomy showed a significant change.

The approach in the third iteration was again empirical-to-conceptual. A larger random sample of 20 other companies was examined to check whether the dimensions and characteristics of the first two iterations were stable enough (i.e. sufficient number and chosen meaningfully). This iteration combined the provision of infrastructures, platforms and software in a public cloud. The development of algorithms for the analysis of data sets and their representation, as well as the development of programs for data security, encryption, and secure communication via the internet are based on the development of mathematical algorithms. These are written programs and therefore similar to each other. So, the newly identified characteristic development of security software was added to the already existing characteristic *software development*. Customer segments such as military, healthcare, etc. were combined into *high security areas*. The largest changes during this iteration step occurred in the dimension revenue stream. It was found that the revenue stream dimension is not entirely accurate for this taxonomy, as the definition provided by Osterwalder and Pigneur (2010) was too imprecise for our taxonomy. In order to describe this dimension more precisely, it was reformulated into *payment model*. In addition, payment models consisting of a combination of several models, such as *one-time payment*, *project* payment, and/or subscription (payment on *time basis*), were combined to *hybrid*. Furthermore, the new characteristic payment on *usage basis* was identified and added to the taxonomy, which is similar to the already existing characteristic payment on *time basis*. In contrast to *time basis*, *usage basis* is billing based on the use of a particular resource (e.g., used computing capacity). In addition, the dimension sales channel was reformulated to *deployment channel*. It was found that a better differentiator is how a customer accesses a service than how it is bought. In the third iteration there was also a significant change in the taxonomy, indicating that the end conditions are not met.

Further 30 companies are examined according to the empirical-to-conceptual approach. It turns out that large companies such as Bosch Rexroth or National Instruments cannot be assigned to a single key activity because they are active in many different areas (consulting, hardware development, software development, etc.). Accordingly, the activities of such companies were combined in *universal range*. Furthermore, the newly identified customer segments logistics, aviation and railway were combined in *logistics/transport industry*, as these segments are similar in their scope. A further customer segment, a combination of *manufacturing industry + energy sector* was identified and added to the taxonomy. In the fourth iteration there was no significant change in the taxonomy, but some characteristics were added, so all end conditions of the taxonomy development are not yet fulfilled.

Finally, the 53 remaining companies in the sample are examined. During this investigation no further dimensions or characteristics were added or changed. Thus, according to Nickerson et al. (2013), the five subjective as well as the eight objective end conditions of the taxonomy development were considered to be fulfilled. Formally, the final taxonomy was exactly the same as the taxonomy after the fourth iteration step.

The Developed Predictive Maintenance Business Model Taxonomy

In the following, we present the final version of the developed taxonomy. Table 1 shows the found dimensions in the first column and the identified characteristics in the respective rows. The first dimension *key activity* describes what the company does primarily according to its business model (Osterwalder et al. 2005, Osterwalder & Pigneur 2010). The second dimension *value promise* describes how customer needs are satisfied and customer problems are solved (Osterwalder et al. 2005, Osterwalder & Pigneur 2010). The dimension *payment model* is defined by how the performance of a PdM provider is measured and billed. For example, the characteristic *project* expresses that it is paid for the execution of a defined project. This is therefore likely to be found frequently in consulting. On the other hand, *time basis* is billed for a certain period of time. For example, for a one month use of a cloud platform. But it is also possible to pay according to the actual use (*usage basis*), for example according to the computing power used. How a product or service is provided to the customer is represented in the dimension *deployment channel*. In order to distinguish the companies according to their *customer segments*, the dimension describes the branch in which the company mainly has its customers (Osterwalder et al. 2005, Osterwalder & Pigneur 2010). The dimension *clients* describes to which type of customer a service is sold. The last dimension *information layer* represents the area a service of the company is provided. The idea for this dimension is based on Chen (2013). The definition of the characteristics of each dimension can be found in Table 6 of the Appendix.

Table 1 Developed taxonomy

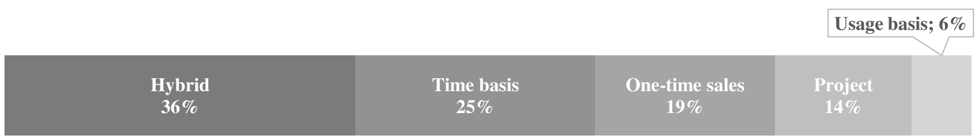
Dimensions	**Characteristics**		
Key activities	1) Hardware development	2) Software development	3) Consulting
	4) Edge computer development	5) Provision of a public cloud	6) Hardware retailer
	7) Universal range	8) Provision of an application platform	
Value promise	1) All-in-one solution	2) Condition monitoring	3) Connectivity
	4) Automation	5) Forecasting	6) Data security
	7) Data storage + software development tools		
Payment model	1) One-time sales	2) Time basis	3) Project
	4) Usage basis	5) Hybrid	
Deployment channel	1) Physically	2) www	3) Physically + www (cloud)
	4) www (cloud) + API	5) www (cloud)	6) Physically + www (cloud) + API
Customer segment	1) Manufacturing industry	2) Energy sector	3) No industry focus
	4) High-security areas	5) Manu. industry + energy sector	6) Manu. industry + Logistics/Transport Industry
Clients	1) B2B	2) B2B + B2B2B	3) B2B + state
Information layer	1) Application and services	2) Information handling	3) Information delivering layer
	4) Object sensing and information gathering layer	5) Multiple	

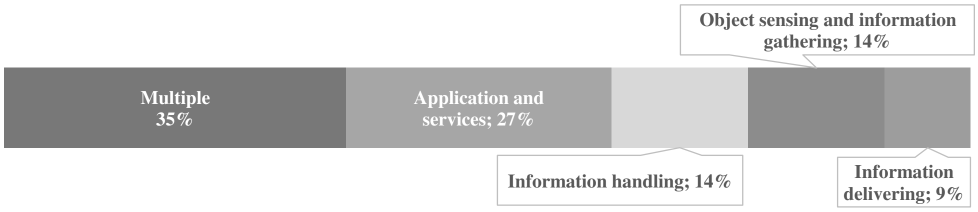
Taxonomy Application

Mapping of the Sample

In order to show the usability of the taxonomy, we assigned all 113 companies of the dataset to their respective characteristics. For all companies, the company website was used as the basis for the mapping. Companies that were identified on the fair website were supplemented with information from the interviews with company representatives. If the Crunchbase database served as a source, first information could be obtained from the short description provided. The mapping of the characteristics of the data set was divided among the authors. In the case of borderline companies, the assignment of further authors was checked. Table 2 shows the distribution in each dimension.

Table 2 Distribution of the characteristics

Dimensions	Distribution
Key activities	
Value promise	
Payment model	
Deployment channel	

<table>
<tr><th>Dimensions</th><th>Distribution</th></tr>
<tr><td>Customer segment</td><td>
</td></tr>
<tr><td>Clients</td><td>
</td></tr>
<tr><td>Information layer</td><td>
</td></tr>
</table>

The dimension *key activity* shows that the different characteristics are relatively evenly distributed with the exception of the characteristics *hardware retailer* and *public cloud offering*. This might be related to the fact that providers of such services do not explicitly advertise a PdM offer and were therefore not part of our data set. The *value promise* is dominated by *condition monitoring*, *forecasting* and *all-in-one solutions*. *Data security* is only weakly represented, which could be due to the fact that companies that specialize in security do not explicitly advertise PdM services. With regard to the *payment model* dimension, it is noticeable that payment on a usage basis still plays a subordinate role. Most companies use *hybrid* forms of payment. In the *deployment channel* dimension, it is noticeable that the *physical* provision of products plays a major role alongside *cloud and software* offerings. Most companies do not have an explicit sector focus. If companies concentrate, they focus primarily on the manufacturing *industry*. The desired business of PdM providers is primarily in a *B2B* environment. An explicit focus on *state* or government organizations is rare. In the *information layer* dimension, about one third of the companies have an offer for several layers. Many companies have offers on the *application and services* layer.

Business Model Clusters

In order to gain a better understanding of the PdM market, we have created archetypes in the PdM environment equivalent to other developments of business model taxonomies (Gimpel et al. 2017, Eickhoff et al. 2017). To this end, we conducted a cluster analysis. Since we have almost identical requirements as in the article by Gimpel et al. (2017), we have also used the Ward's (1963) algorithm for clustering. Ward's (1963) algorithm is a hierarchical cluster algorithm with the advantage that not only a predefined number of clusters are formed, but all possible ones (Gimpel et al. 2017, Backhaus et al. 2011). We have also used the Sokal and Michener (1958) matching coefficient as a distance measure. As Gimpel et al. (2017) describe, there are now various algorithms with which the suitable number of clusters can be determined. Depending on the algorithm, the results can be quite different. For this reason, we first take a graphical look at the result of the Ward algorithm (Täuscher & Laudien 2018). It is shown in Figure 2. Three different clusters can be identified at the first, upper two branches. After looking at the companies assigned to the respective clusters, the groups can be named with the following three labels: "Universal vendors", "Software and platforms", "Hardware and consulting". From our point of view this naming showed that the groups were not yet granular enough. The next branching would lead to four groups. Since the height and thus the distance of the groups is close to the next two branches, we did not analyze four, but six groups in the next step. These groups are marked red in Figure 2.

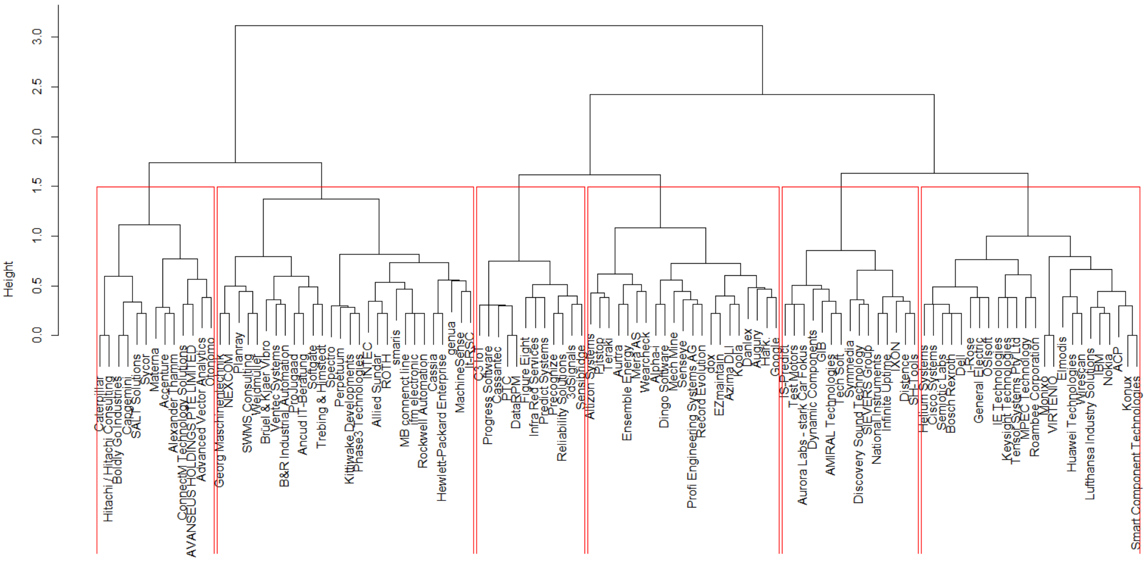


Figure 2 Result of the Ward clustering visualized by a dendrogram

After analyzing the companies of the six different groups, we come to the following labels for the clusters formed: "Consulting", "Hardware development", "Platform provider", "Information manager", "Analytics provider", and "All-in-one". We then examined a subdivision into seven groups. However, this rather leads to a deterioration of the cluster results. So we came to the conclusion that a subdivision into six groups is the most reasonable. In addition to hierarchical cluster algorithms, partitioning algorithms are also available for the final allocation of companies to the six clusters. Following the approach of Hartmann et al. (2016), we look at a cluster creation using the k-means and the k-medoids algorithms. The k-medois has the advantage that it does not react as strongly to outliers as the k-means algorithm (Hartmann et al. 2016). The decision on the quality of the assignment of the two algorithms was made by analyzing the distribution of the characteristics in each group. Like in the research by Hartmann et al. (2016), the k-medoids algorithm leads to better results which are shown in Table 3.

Table 3 shows the clear differentiation of the formed groups in the first dimension (*key activities*). At least 61% of a group were assigned to the same characteristic. Based on the *key activities* we also named the groups. For the archetypes four and six, we have also included other dimensions in the naming, especially the second and seventh dimension. The *hardware development* group also includes some of the companies that develop *edge devices*. The main value proposition (D2) is *condition monitoring*, but *automation and connectivity* also play a role. The business is mainly conducted through *one-time sales* (D3) and therefore the *deployment channel* (D4) is *physical*. Most companies do not have a specific industry focus, but if so in the *manufacturing industry*. Customers are mainly in the *B2B* segment. All companies that explicitly mention the *state* as a customer are part of the *hardware development* group. The majority of companies work on the *object sensing and information gathering* layer.

The *platform provider* group comprises vendors of application platforms (D1) with a focus on *forecasting* models (D2). They enable these developments with a *hybrid payment model* (D3). Since some vendors do this in combination with *consulting* services and special *hardware devices*, the *deployment channel* (D4) is both *physical* and via a *cloud* platform. In this group a focus on the manufacturing *industry* can be seen (D5). The customers are in the *B2B* environment (D6) and the companies mainly operate in the *application and services* layer (D7).

Table 3 Results of the cluster analysis

		Hardware development	*Platform provider*	*All-in-one*	*Information manager*	*Consulting*	*Analytics provider*
		1	2	3	4	5	6
D1	Provision of an application platform		64%	6%		7%	35%
	Edge computer development	17%		10%	67%		
	Hardware development	63%					
	Hardware retailer	8%					
	IT consulting			6%	17%	87%	
	Provision of a public cloud			3%			4%
	Software development	8%	21%	6%	17%	7%	61%
	Universal range	4%	14%	68%			
D2	Automation	17%	7%			7%	
	Data storage + software development tools	4%		13%	17%		13%
	All-in-one solution	8%		55%	17%	27%	9%
	Forecasting	8%	57%	3%	17%	20%	52%
	Data security	8%					
	Connectivity	13%	14%	13%		7%	
	Condition monitoring	42%	21%	16%	50%	40%	26%
D3	Usage basis		21%	6%		7%	4%
	Time basis		7%	19%	17%		87%
	One-time sales	83%		3%			
	Hybrid	13%	64%	71%	83%		9%
	Project	4%	7%			93%	
D4	Physically	83%		13%	33%	87%	4%
	Physically + www (cloud)	4%	36%	65%	50%		13%
	Physically + www (cloud) + API	4%		10%		7%	
	www	8%	14%	3%	17%		13%
	www (cloud)		36%	3%			43%
	www (cloud) + API		14%	6%		7%	26%
D5	Energy sector	8%	7%	3%	17%		9%
	High-security areas	4%					
	Industry	29%	57%	16%	67%	33%	22%
	Industry + energy sector	8%	14%	13%	17%	7%	
	Industry + logistics/transport industry	4%	7%	6%		7%	9%
	No industry focus	46%	14%	61%		53%	61%
D6	B2B	71%	71%	74%	67%	67%	83%
	B2B + B2B2B	17%	29%	26%	33%	27%	17%
	B2B + State	13%				7%	
D7	Application and services		71%	6%		60%	43%
	Information delivering	17%		3%	33%		13%
	Information handling	4%	21%	13%		7%	30%
	Multiple	25%		74%	50%	33%	13%
	Object sensing and information gathering	54%	7%	3%	17%		

Note: Due to rounding inaccuracies, the sum of a column in a dimension is not always exactly 100%.

Various activities are offered by companies which are assigned to the *all-in-one* group (D1). Mainly they promise an *all-in-one* solution (D2). Their *payment model* is *hybrid* (D3) and the *deployment channel* is both *physical* and via *cloud* solutions (D4). There is no specific customer segment (D5) and the customers are in the B2B environment (D6). The companies are active on all information layers (D7). The *all-in-one* group is the largest group in the investigated data set.

In contrast, the *information manager* group is the smallest one in the data set. In this group there are mainly companies that *develop edge devices*, but also *software development* and *consulting* play a role (D1). The most common *value promise* is the realization of *condition monitoring* (D2). The *payment model* (D3) and the *deployment channel* (D4) are equal to the *all-in-one* group (*hybrid and physically + www (cloud)*). In the *information manager* group there is a focus on *industrial* companies (D5). The group's customers are not only *B2B* customers, but one third also constitute *B2B2B* relationships (D6). Half of the companies are active on *multiple* information layers. Another third takes care of the *information delivering* (D7).

We call the fifth cluster the *consulting* group. Obviously the *key activity here* is *consulting* (D1). The *value proposition* is *condition monitoring* (D2) and the payment is *project*-based (D3). Above all, consulting services are sold. Since a consulting service cannot currently be provided automatically via a cloud or software, the *deployment channel* is primarily *physically* (D4). There is no special customer focus (D5) and *B2B* customers are addressed (D6). The consulting is mainly done in the area of *application and services* but one third of the companies operate on *multiple* layers (D7).

The last group *analytics provider* mainly deals with *software development* but also the *provision of application platforms* plays a role (D1). The *value promise* lies above all in the creation of *forecasts* (D2). The billing takes place on a *time basis* (D3) and the provision of a service via *cloud* (D4). There is no industry focus (D5) and the users are *B2B* customers (D6). Mostly, companies are active on the *application and services* layer, but *information handling* is also often found. The groups described are summarized in Table 4.

Table 4 Found PdM business model archetypes

	Archetype					
	1	**2**	**3**	**4**	**5**	**6**
Label	*Hardware development*	*Platform provider*	*All-in-one*	*Information manager*	*Consulting*	*Analytics provider*
Key activities	Hardware development	Provision of an application platform	Universal offer	Edge computer development	Consulting	Software development
Value promise	Condition monitoring	Forecasting	All-in-one solution	Condition monitoring	Condition monitoring	Forecasting
Payment model	One-time sales	Hybrid	Hybrid	Hybrid	Project	Time basis
Deployment channel	Physically	Physically + www (cloud)	Physically + www (cloud)	Physically + www (cloud)	Physically	www (cloud)
Customer segment	No industry focus	Manufacturing industry	No industry focus	Manufacturing Industry	No industry focus	No industry focus
Clients	B2B	B2B	B2B	B2B + B2B2B	B2B	B2B
Information layer	Object sensing and information gathering	Application and services	Multiple	Multiple & information delivering	Application and services	Application and services & information handling
Share in sample (113)*	21%	12%	27%	5%	13%	20%
Example company	Rockwell Automation	Test Motors	National Instruments	IXON	Hitachi Consulting	Senseye

*Due to rounding inaccuracy the sum is not exactly 100%

In order to better understand the different groups and their connections between each other, we visualize the firms in a two-dimensional coordinate system. Representing all characteristics of the firms in a two-dimensional space requires a dimensionality reduction technique which takes into account the dependencies and possible non-linear relationships between them. In this paper we use an autoencoder with three hidden layers (10-2-10 neurons) which uses all characteristics of the firms as input features (Hinton 2006). The structure of hidden neurons compresses the information of the input to two dimensions in the latent space of the network which can be used for a two-dimensional scatter plot. Figure 3 shows the resulting representation. Each firm is visualized by a dot in the coordinate system while the color indicates the affiliation of the firms based on the k-medois clustering.

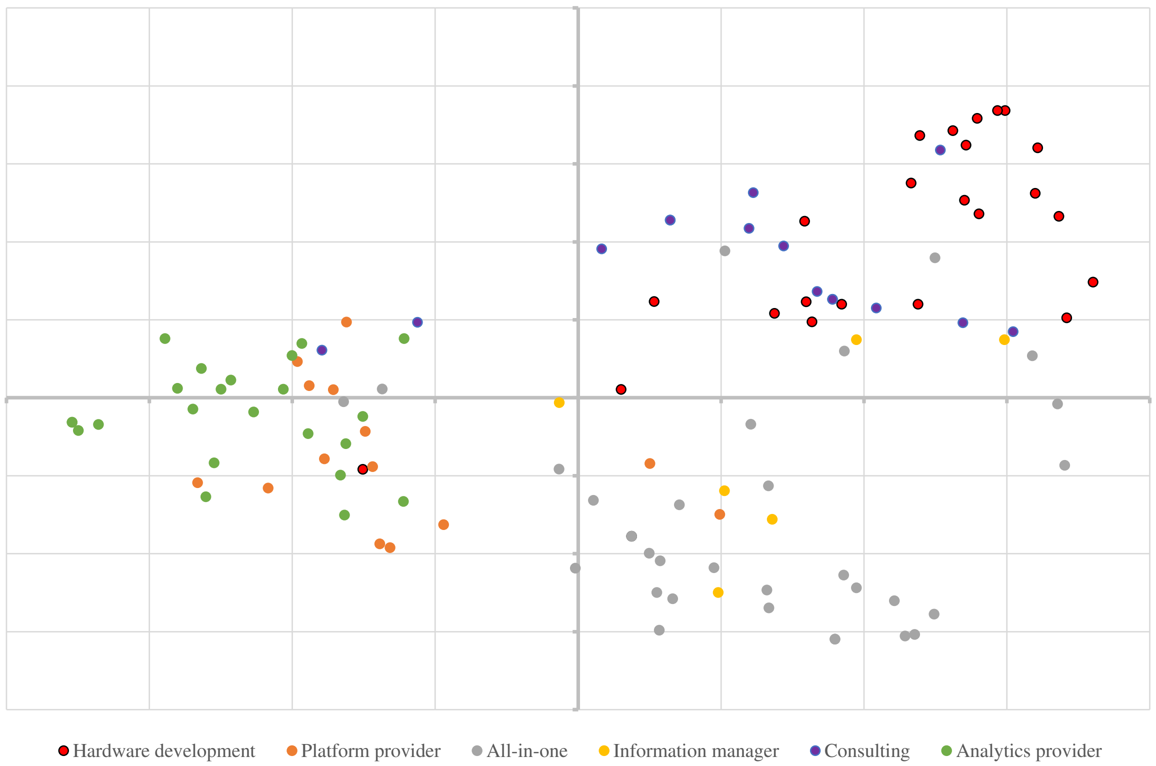


Figure 3 Visualization of the clustering using an autoencoder method

Initially, three large groups can be identified in the visualization. In the range x<-0.2, in the quadrant x>0, y<0 and the group x, y > 0. In our analysis, we found that the composition of these three groups is approximately 80% consistent with the allocation of the three largest groups of the Ward algorithm, as shown in Figure 2. It can be seen that companies of the *all-in-one* group are represented in all areas. This shows that there are generalists with different focuses. Nevertheless, the companies of this group are clustered in one point, because the companies usually distinguish themselves from the other groups by the first two dimensions, *key activities* and *value promise*. A similarity between companies in the *analytics and platform provider* groups can also be seen. This coincides with our experience in assigning the characteristics and is shown in table 4. Both groups are primarily concerned with the creation of *forecasts*, both operate in the *application and software* layer and either *software development* or the use of software or a *cloud platform* is sold. The groups *consulting* and *hardware development* also seem to be similar. On closer inspection, however, it can be seen that the distances are much greater than between *analytics* and *platform provider*. In both groups, companies have *condition monitoring* as the majority *value promise* and *physically* as *deployment channel*. However, the dimension *information layer* expresses the fact that the companies in the respective groups have different offers.

Discussion, Implications, and Recommendations

The cluster analysis has shown the PdM business model archetypes which are currently practiced. A similarity to the archetypes found during the investigation of data-driven business models is noticeable (Hartmann et al. 2016). When considering data-driven business models, the data source plays a decisive role in addition to general aspects of a business model like the key activities or the value promise. The data source plays small role in the developed taxonomy, since the data comes from the respective customers. Instead, the business models can be differentiated according to layers of an IoT architecture. But also in the data driven business models there is a distinction between "data-aggregation-as-a-service" and "analytics-as-a-service" similar to the archetypes *platform and analytics provider* found in this study (Täuscher & Laudien 2018). *Analytics providers* offer the analysis of customer data and develop software for this purpose, while *platform providers* only provide the prerequisites for further analyses. The *analytics provider* does not only act on the *application and services* layer, but takes also care of the *information handling*. In addition to these archetypes, there are also hardware developers, consultants and generalists in the PdM environment. When considering the sample companies assigned to the archetype *hardware development*, we found companies (e.g., ROTH) that address the problem that older machines are not yet internet-capable. Here hardware is needed to enable further analysis for PdM. In parallel, the presence of the *all-in-one* archetype supports the insight by Dijkman et al. (2015) that it is important for IoT business models to be convenient, usable and "getting the job done" (Dijkman et al. 2015, p. 676). *All-in-one* offers seem to address this demand. For example, in addition to the software for analyzing the collected data, the company National Instruments supplies various monitoring devices for recording different sensors. The existence of consulting firms shows that certain use cases are complex and/or additional resources are needed for realizing PdM use cases.

The developed taxonomy allows an initial classification of a concrete IoT business model, namely a PdM business model. It was found that many elements of the taxonomy are similar to other taxonomies. For example, there are often the dimensions *value proposition* and *key activities* (e.g., Hartmann et al. 2016, Eickhoff et al. 2017, Täuscher & Laudien 2018). However, the respective characteristics and the dimension *information layer* are different. The differentiation of the sample companies according to the IoT layers was important in order to identify the differences between the individual PdM business models.

Our research also has implications for practice. Information about which dimensions are important when considering PdM business models are provided by the taxonomy. It allows companies to classify their own business model and the models of other companies facilitating a comparison. The found archetypes support these comparisons. Companies can also use the archetypes to identify whether their PdM offering is rare or common on the market. This assessment simplifies a specialization. But also companies that simply want to use PdM services can profit from the results of our research. As Dijkman et al. (2015) have already concluded for IoT business models, it is important for companies to understand how others make money in the ecosystem. The results of our study contribute to the understanding of PdM business models and thus companies can optimize their networks or ecosystems.

The archetypes *hardware development*, *analytics provider, and all-in-one* are most strongly represented in the investigated data sample. In contrast, there are few companies of the *information manager* type. There could be three reasons for this: First, there are currently few companies that pursue such a business model. This would mean that there is still a gap in the market that offers growth opportunities for companies. Second, there are many companies with a similar business model, but they do not promote this offer under the terms "condition monitoring" and "predictive maintenance". For such companies, extended or modified marketing could make sense. Third, there is no demand for it because companies do not need specific solutions or use their own solutions.

Visualizing the assigned sample companies using an autoencoder offers, besides using a dendrogram, another possibility to visualize the similarities of the companies. In our case the dendrogram was better suited to identify a meaningful number of groups, while the two dimensional chart better represents the distances and overlaps of the respective groups. From our experience, a combination of both methods is an efficient approach for the formation and interpretation of archetypes.

Limitations and Further Research

In addition to the knowledge gained from this research, the limitations of this research must also be mentioned. The taxonomy depends on the definition of PdM. On the basis of existing literature, we comprehensively defined PdM and regarded for example "condition monitoring" as a part of PdM. If PdM is defined differently, a different taxonomy results. The size of the used sample is limited. This is particularly evident in the cluster analysis when analyzing the cluster *information manager*. Only 5% of the sample were assigned to this cluster, which makes the cluster very small and therefore hardly interpretable. Further research with more data is desirable in this area as it simplifies the description and thus the analysis of this archetype.

The sample also only includes companies that can be found under the terms “predictive maintenance” or “condition monitoring”. There can be companies that have a PdM-like offer, but do not name it explicitly and thus cannot be found. We have tried to counteract this by using overview online articles as a source for the companies under investigation. However, many companies in these articles have explicitly used the PdM term as well. Also, some companies describe only roughly what their offers look like. We have tried to counter this problem through the analysis of borderline companies by several authors.

The newly used visualization with the partial use of an autoencoder procedure is a first attempt to visualize the assignment of business models according to a taxonomy. In our case, this has led to interesting insights and made the PdM market transparent. Further research is needed to gain more experience with this process and to determine whether it can provide useful insights generally.

Our research is only a momentary snapshot. Especially the found archetypes must be checked again after a certain time, because the market is dynamic and changes are conceivable. Furthermore, new technologies have the potential to significantly change the market situation. Thus, the taxonomy will also change over time. Additional characteristics may be added and even the consideration of further dimensions can become necessary. But then our taxonomy offers a starting point for further development.

Conclusions

Our research presents a taxonomy for the classification of PdM business models. It is the basis for a classification of different providers of PdM solutions. To create the taxonomy, a data set of 113 companies was examined. In a further step, the business models were described on the basis of the taxonomy. Using a cluster analysis it could be examined which archetypes of PdM business models currently exist. Six different archetypes were identified. The analysis of the archetypes shows that not only the general business model dimensions of the Business Model Canvas (Osterwalder & Pigneur 2010) are important for the differentiation, but also the inclusion of an IoT architecture (Chen 2013). There are PdM offers for all four layers of the architecture, whereby the layer information delivering is underrepresented in the data set examined. Although PdM services are very diverse, our study has shown that PdM business models can be divided into six archetypes. This insight allows in theory and practice to better understand PdM business models.

In addition to the findings about the PdM business models, a partially applied autoencoder procedure was used to visualize the assigned business models. This was valuable to better understand the different archetypes and their relationships. In combination with a dendrogram, this visualization enabled an analysis of the clusters formed. The procedure can be transferred to other studies and contributes to an efficient analysis there.

Appendix

Content of the Interviews

The following points were addressed in the interviews:

- Company name
- Position in the company (of the interviewee)
- Key activities
- Payment model
- Sales channel
- Customers
- Customer segment
- Value proposition for the customer
- Return of Invest for the customer
- Opinion regarding the expected market development

Iterations and End Conditions

Table 5 Summary of fulfilled end conditions per iteration based on Nickerson et al. (2013)

Iteration					Ending conditions
1. con.*	2. emp.*	3. emp.*	4. emp.*	5. emp.*	
	x	x	x	x	Concise
	x	x	x	x	Robust
			x	x	Comprehensive
x	x	x	x	x	Extendible
				x	Explanatory
				x	All objects or a representative sample of objects have been examined
x	x	x	x	x	No object was merged with a similar object or split into multiple objects in the last iteration
	x	x	x	x	At least one object is classified under every characteristics of every dimension
				x	No new dimensions or characteristics were added in the last iteration
				x	No dimensions or characteristics were merged or split in the last iteration
x	x	x	x	x	Every dimension is unique and not repeated (i.e., there is no dimension duplication)
	x	x	x	x	Every characteristic is unique within its dimension (i.e., there is no characteristic duplication within a dimension)
	x	x	x	x	Each cell (combination of characteristics) is unique and is not repeated (i.e., there is no cell duplication)

*con. = conceptual, emp. = empirical

Definitions of the Characteristics Used

Table 6 Dimensions, characteristics and their definitions

Dim.	Characteristic	Definition
D1 – Key activities	1) Hardware development	Hardware development describes the development and manufacture of technical machine elements.
	2) Software development	Software development describes the development/adaptation of programs of data processing systems.
	3) Consulting	Advising companies on the design, implementation and improvement of processes and solutions.
	4) Edge computer development	It describes the development of systems for decentralized data acquisition/data processing at the edge of the network (also called "Fog Computing"). Can occur in combination with the use of a cloud. Can include both software and hardware development, but with a clear focus on edge computing.
	5) Provision of a public cloud	Provision of a computing and/or storage infrastructure accessible via the internet.
	6) Hardware retailer	Purchases hardware components from various smaller manufacturers and distributes them to larger companies (occurs mainly in Asia; smaller, less well-known manufacturers use this to sell their products globally).
	7) Universal range	Broadly based businesses with multiple key areas of activity.
	8) Provision of an application platform	An application platform is a framework of services on which applications depend for standard operations. The platform includes operating systems, execution services, data services, cloud services and development tools.
D2 – Value promise	1) All-in-one solution	Includes complete software and hardware solutions from sensors to data storage to data analysis.
	2) Condition monitoring	Storage, analysis and display of machine data in real time (data must be provided).
	3) Connectivity	Provision of hardware and software components for setting up systems (e.g., routers, network cables, etc.).
	4) Automation	Provision of hardware components that enable the transfer of functions of the production process from humans to artificial systems (e.g., sensors). Components that enable a "retrofit".
	5) Forecasting	Forecast of machine or component lifetimes or lifetimes of a machine part (e.g., section, component).
	6) Data security	Includes the provision of security technology in the areas of hardware and software (e.g., fire-resistant hardware components, encryption programs, etc.) for the implementation of predictive maintenance.
	7) Data storage + software development tools	Provides large amounts of disk space and tools to create, debug, diagnose, and manage software.
D3 – Payment model	1) One-time sales	Product/service is paid once.
	2) Time basis	Product/service is paid for on the basis of its usage period or at regular intervals (e.g., subscription or license for one year).
	3) Project	Product/service is paid within the scope of a project, after the project no further costs are charged for the service provided or for owning the developed output.
	4) Usage basis	Product/service is paid on the basis of the amount of services used, the number of uses, the computing needs, etc.
	5) Hybrid	Combination of two or more payment models.
D4 – Deployment channel	1) Physically	Provision of the product/service/hardware takes place physically (e.g., by implementing/installing software or hardware on site, consulting, etc.).
	2) www	Product/service can be downloaded or used via the Internet.
	3) Physically + www (cloud)	Combination of physical provision of products/services (see description "physical") and use of services on a cloud accessible via the Internet.
	4) www (cloud) + API	Use of the product/service on a cloud accessible via the Internet. A programming interface is also provided.
	5) www (cloud)	Use of the product/service on a cloud accessible via the Internet.
	6) Physically + www (Cloud) + API	Combination of previous characteristics (see above).
D5 – Customer segment		A more detailed definition of the segments is not necessary.

Dim.	Characteristic	Definition
D6 – Clients	1) B2B	Selling products, services or products to other companies. No sales to end customers.
	2) B2B + B2B2B	Combination of B2B (see above) and Business-to-Business-to-Business (B2B2B). B2B2B is a B2B activity in which the customer of the company in question sells platform services to other companies (e.g., a company rents platform services and then sells them as services in addition to its product).
	3) B2B + State	Companies sell products/services to customers in the public sector (e.g., military). This occurs in combination with B2B (see above).
D7 – Information layer	1) Application and services	Applications and services that use the acquired data (e.g., sensor data), e.g., for an analysis or forecast of the future deterioration of a machine (Chen 2013).
	2) Information handling	Processing of data and/or provision of computing capacity (Chen 2013)
	3) Information delivering layer	Transport and/or networking of information (Chen 2013).
	4) Object sensing and information gathering layer	Provision of sensors, data extraction and/or collection of information (Chen 2013).
	5) Multiple	When activities take place on more than one layer.

Predictive Maintenance Companies Sample

Table 7 Company sample with name of the company, website, and source

Company	Website	Source
3dSignals	http://www.3dsig.com	Crunchbase Predictive Maintenance
Accenture	https://www.accenture.com/us-en/service-accenture-corrosion-management-services	Website List
ACP	https://www.acp.de	Hannover Industrie Messe 2018
Advanced Vector Analytics	http://www.ava-labs.com/	Crunchbase Condition Monitoring
Alexander Thamm	https://www.alexanderthamm.com/de/	Website List
Allied Sundar	http://www.sundar.com.tw/	Hannover Industrie Messe 2018
Alpha-i	http://alpha-i.co/	Crunchbase Predictive Maintenance
Altizon Systems	http://altizon.com/	Crunchbase Webpage Search
AMIRAL Technologies	https://www.amiraltechnologies.com/en/	Hannover Industrie Messe 2018
Ancud IT-Beratung	https://www.ancud.de/	Hannover Industrie Messe 2018
Augury	http://www.augury.com	Crunchbase Predictive Maintenance
Aurora Labs - stark Car Fokus	https://www.auroralabs.com/	Crunchbase Webpage Search
Aurtra	https://www.aurtra.com.au	Crunchbase Condition Monitoring
AVANSEUS HOLDINGS PTE LIMITED	http://www.avanseus.com/	Crunchbase Predictive Maintenance
Azima DLI	http://www.azimadli.com	Crunchbase Condition Monitoring
B&R Industrial Automation	https://www.br-automation.com/	Hannover Industrie Messe 2018
Boldly Go Industries	https://www.boldlygo.de	Hannover Industrie Messe 2018
Bosch Rexroth	https://www.boschrexroth.com/en/xc/service/industrial-applications/predictive-maintenance/predictive-maintenance-2	Website list
Brüel & Kjaer Vibro	https://www.bkvibro.com	Hannover Industrie Messe 2018
C3 IoT	https://c3iot.ai/	Crunchbase Webpage Search
Capgemini	https://www.capgemini.com	Hannover Industrie Messe 2018
Cassantec	https://casantec.com/	Website List
Cassia	https://www.cassianetworks.com/	Hannover Industrie Messe 2018
Caterpillar	https://www.cat.com/de_DE/support/maintenance/condition-monitoring.html	Website List
Cisco Systems	https://www.cisco.com/c/en/us/solutions/internet-of-things/overview.html	Website List
ConnectM Technology Solutions	http://www.connectm.com	Crunchbase Condition Monitoring

Company	Website	Source
Danlex	http://www.danlex.com	Crunchbase Predictive Maintenance
DataRPM	http://www.datarpm.com/	Crunchbase Webpage Search
Dell	http://www.dell.com/en-us/work/learn/internet-of-things-solutions#Why-choose-Dell?	Website List
Dingo Software	http://www.dingo.com	Crunchbase Predictive Maintenance
Discovery Sound Technology	http://www.discoverysoundtechnology.com	Crunchbase Predictive Maintenance
Distence	https://www.distence.fi/de	Hannover Industrie Messe 2018
dox	http://dox.tech	Crunchbase Predictive Maintenance
Dynamic Components	http://www.dynamic-components.de	Crunchbase Predictive Maintenance
Elmodis	http://www.elmodis.com/	Crunchbase Webpage Search
Ensemble Energy	http://www.ensembleenergy.ai	Crunchbase Predictive Maintenance
EZmaintain	https://www.ezmaintain.com	Crunchbase Predictive Maintenance
Figure Eight	https://www.figure-eight.com/	Crunchbase Webpage Search
General Electric	https://www.ge.com/digital/sites/default/files/Predix-from-GE-Digital-Overview-Brochure.pdf	Website List
genua	https://www.genua.de	Hannover Industrie Messe 2018
Georg Maschinentechnik	http://www.georg-maschinentechnik.de/	Hannover Industrie Messe 2018
GIB	https://www.gibmbh.de/en/	Hannover Industrie Messe 2018
Google	https://cloud.google.com/	Hannover Industrie Messe 2018
Hark.	https://harksys.com	Crunchbase Predictive Maintenance
Helium Systems	https://www.helium.com/solutions/manufacturing	Website List
Hewlett-Packard Enterprise	https://www.hpe.com/de/de/solutions/industrial-internet-of-things.html	Hannover Industrie Messe 2018
Hitachi / Hitachi Consulting	https://www.hitachiconsulting.com/solutions/hitachi-predictive-maintenance.html	Website List
Huawei Technologies	https://e.huawei.com/en/solutions/business-needs/enterprise-network/agile-iot/elevators-connection	Website List
IBM	https://www.ibm.com/us-en/marketplace/ibm-predictive-maintenance-optimization	Website List
IE Technologies	http://www.ietechnologiesllc.com	Crunchbase Predictive Maintenance
ifm electronic	https://www.ifm.com/	Website List
Infinite Uptime	http://www.infinite-uptime.com/	Crunchbase Webpage Search
Infra Red Services	http://www.infraredservices.com.au	Crunchbase Condition Monitoring
INTEC	https://www.intec-connectivity.com/	Hannover Industrie Messe 2018
i-Rose	http://www.i-rose.si	Crunchbase Predictive Maintenance
IS-Predict	http://www.ispredict.com/	Hannover Industrie Messe 2018
It-RSC	https://it-rsc.de/	Hannover Industrie Messe 2018
IXON	https://www.ixon.cloud/de	Hannover Industrie Messe 2018
Keysight Technologies	https://www.keysight.com/de/de/home.html	Website List
Kittiwake Developments	http://www.kittiwake.com	Crunchbase Condition Monitoring
Konux	https://www.konux.com/de/	Website List
Koola	http://www.koola.io	Crunchbase Predictive Maintenance
Lufthansa Industry Solutions	https://www.lufthansa-industry-solutions.com/de-en/	Hannover Industrie Messe 2018
MachineSense	https://machinesense.com/	Crunchbase Predictive Maintenance
Materna	https://www.materna.de/	Hannover Industrie Messe 2018
MB connenct line	https://www.mbconnectline.com/	Hannover Industrie Messe 2018
Mech Mine	https://www.mechmine.com/en/	Hannover Industrie Messe 2018
Mera AS	http://www.mera.no	Crunchbase Condition Monitoring
Monixo	http://www.monixo.com	Hannover Industrie Messe 2018

Company	**Website**	**Source**
MPEC Technology	http://www.mpec.co.uk	Crunchbase Condition Monitoring
National Instruments	http://www.ni.com/de-de/innovations/industrial-machinery/condition-monitoring.html	Website List
NEXCOM	http://www.nexcom.com/	Hannover Industrie Messe 2018
Nokia	https://spacetimeinsight.com/asset-analytics/	Website List
OSIsoft	https://www.osisoft.com/iiot/	Website List
Otonomo	http://www.otonomo.io/	Crunchbase Webpage Search
Perpetuum	http://www.perpetuum.com	Crunchbase Condition Monitoring
Phase3 Technologies	http://www.phase3-tech.com/	Crunchbase Predictive Maintenance
Pitstop	https://www.pitstopconnect.com	Crunchbase Predictive Maintenance
Planray	http://www.planray.com/en/	Hannover Industrie Messe 2018
Precognize	http://www.precog.co	Crunchbase Predictive Maintenance
Predict Systems	http://predictsystems.com	Crunchbase Predictive Maintenance
Profi Engineering Systems AG	https://www.profi-ag.de/	Hannover Industrie Messe 2018
Progress Software	https://www.progress.com/solutions/cognitive-predictive-maintenance	Website List
ProJugaad	http://projugaad.com	Crunchbase Predictive Maintenance
PTC	https://www.ptc.com/en/products/iot/thingworx-platform/analyze	Website List
Record Evolution	https://record-evolution.de/	Hannover Industrie Messe 2018
Reliability Solutions	http://reliasol.pl/en/	Crunchbase Predictive Maintenance
Roambee Corporation	http://www.roambee.com	Crunchbase Condition Monitoring
Rockwell Automation	https://ab.rockwellautomation.com/Condition-Monitoring	Website List
ROTH	https://www.roth-gruppe.de/	Hannover Industrie Messe 2018
SALT Solutions	https://www.salt-solutions.de/	Hannover Industrie Messe 2018
Semiotic Labs	http://www.semioticlabs.com	Crunchbase Condition Monitoring
Senseye	http://www.senseye.io/	Hannover Industrie Messe 2018
Sensibridge	http://sensibridge.com/	Crunchbase Predictive Maintenance
SH-Tools	https://www.sh-tools.com/de/	Hannover Industrie Messe 2018
SIEVERS Group	https://www.sievers-group.com/	Hannover Industrie Messe 2018
smaris	https://www.smaris.cz/	Hannover Industrie Messe 2018
Smart Component Technologies	https://smartcomptech.com	Crunchbase Condition Monitoring
Softgate	https://www.soft-gate.de/	Hannover Industrie Messe 2018
Spectro	http://www.spectroinc.com	Crunchbase Condition Monitoring
SWMS Consulting	https://www.swms.de/consulting/	Hannover Industrie Messe 2018
Sycor	https://de.sycor-group.com/	Hannover Industrie Messe 2018
Symmedia	https://www.symmedia.de/	Hannover Industrie Messe 2018
Tech Soft	https://www.techsoft.at/	Hannover Industrie Messe 2018
Tensor Systems Pty Ltd	http://www.tensorsystems.com	Crunchbase Condition Monitoring
Teraki	http://www.teraki.com	Crunchbase Predictive Maintenance
Test Motors	http://www.testmotors.com	Crunchbase Predictive Maintenance
Trebing & Himstedt	https://www.t-h.de/	Hannover Industrie Messe 2018
Ventec Systems	http://www.ventech-systems.com	Crunchbase Condition Monitoring
VIRTENIO	https://www.virtenio.com/de/	Hannover Industrie Messe 2018
Wearcheck	http://www.wearcheck.co.za	Crunchbase Condition Monitoring
Weidmüller	https://www.weidmueller.de/	Hannover Industrie Messe 2018
Wirescan	http://www.wirescan.no	Crunchbase Condition Monitoring

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Appendix A12

Knowledge Management Systems' Design Principles for Smart Services

Sonja Dreyer, Daniel Olivotti and Michael H. Breitner

Unpublished

Abstract:

Smart services became increasingly important in the last years. The provision of smart services in addition to current product portfolios is advantageous. Smart services are individual services adapted to customers' requirements resulting in strong relationships between customers and smart services' providers. To react immediately to changing requirements, various and frequently changing data must be collected and analyzed. Specific knowledge is necessary to turn data into valuable information. Smart services are usually provided in value networks and participants have different, domain-specific knowledge. Additionally, knowledge is generated during the operation of smart services. A knowledge management system (KMS) adapted to requirements of provided smart services is necessary to aggregate, maintain and provide knowledge. Little research is available in the field of KMS for smart services (KMSSS). Although some publications emphasize the importance of knowledge for smart services, an overview how tailored KMSSS can be designed is missing. A comprehensive literature review is carried out and directly or indirectly named requirements for knowledge management are extracted. Smart services are highly complex which is why requirements differ: there is not the only one best solution for the design of a KMSSS. Therefore, we develop a cubic reference model and show a tailored KMSSS in practice.

Knowledge Management Systems' Design Principles for Smart Services

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Smart services became increasingly important in the last years. The provision of smart services in addition to current product portfolios is advantageous. Smart services are individual services adapted to customers' requirements resulting in strong relationships between customers and smart services' providers. To react immediately to changing requirements, various and frequently changing data must be collected and analyzed. Specific knowledge is necessary to turn data into valuable information. Smart services are usually provided in value networks and participants have different, domain-specific knowledge. Additionally, knowledge is generated during the operation of smart services. A knowledge management system (KMS) adapted to requirements of provided smart services is necessary to aggregate, maintain and provide knowledge. Little research is available in the field of KMS for smart services (KMSSS). Although some publications emphasize the importance of knowledge for smart services, an overview how tailored KMSSS can be designed is missing. A comprehensive literature review is carried out and directly or indirectly named requirements for knowledge management are extracted. Smart services are highly complex which is why requirements differ: there is not the only one best solution for the design of a KMSSS. Therefore, we develop a cubic reference model and show a tailored KMSSS in practice.

Keywords:

Smart services, Knowledge management systems (KMS), Customer-centric design principles, Reference model

1 Introduction

Offering services in addition to products or offering services that make buying products obsolete, becomes more and more important (Oliva and Kallenberg 2003; Böhmann et al. 2018). Smart services arise because they use opportunities resulting from digitalization and the Internet of Things (Georgakopoulos and Jayaraman 2016). Smart services are individual services that can adapt themselves to the environment (Beverungen et al. 2017). To be able to offer smart services efficiently, a comprehensive and reliable knowledge management is required (Zhang et al. 2012; Al Nuaimi et al. 2015,), including, e.g., mathematical models and rules. Knowledge management describes the handling of all kind of knowledge (Fahey 2001).

Knowledge management is especially important for smart services because environment and requirements related to smart services can change immediately (Oh et al. 2010). It is necessary to react to changing conditions because this distinguishes smart services from other types of services. Smart services can only be provided successfully if information and knowledge are available where and when required (Beverungen et al. 2017). For interpreting sensor data, knowledge is necessary. A knowledge management system (KMS) is a prerequisite to be able to react individually (Li et al. 2015). Depending on the specific smart services the designs of KMS for smart services (KMSSS) differ.

In a connected world, knowledge management is not anymore limited to a department or a company. A whole value network must be included (Abbate et al. 2015; Delfanti et al. 2015). As the research field of smart services is a relatively new one, there is only a little number of publications focusing on tailored KMSSS. Although some authors emphasize the importance of a reliable knowledge management for providing smart services successfully (e.g., Wang et al. 2011), in most publications they do not focus on it. An overview showing what are characteristics and key capabilities of KMSSS is still missing. But, it contributes to a better understanding what makes smart services successful. A systematic approach investigates how tailored KMSSS can be designed. Smart services are diverse, and this is reflected in diverse, tailored knowledge management approaches. Therefore, we formulated the following research question:

RQ: How can customer-centric knowledge management systems for smart services be designed?

To answer our research question, we conduct a comprehensive literature search in the field of smart services, using a Webster and Watson (2002) oriented approach. As smart services are knowledge-intensive services (Chu and Lin 2011) all publications contained requirements regarding customer-centric knowledge management processes and information systems (IS) for smart services. These requirements were either formulated explicitly or implicitly. We analyzed the requirements in form of characteristics, functional capabilities, and technical conditions. We developed a reference model that illustrates the diversity of tailored KMSSS designs and design principles.

The paper is structured as follows: In the second section smart services and KMS are outlined and combined subsequently to KMSSS. The third section explains our research design. Our KMSSS reference model is developed afterwards, showing the diversity of design possibilities. It is followed by a discussion of our results, analyzing the influence of knowledge management on organizations and vice versa, too. Design principles are also presented. The paper ends with our limitations, our conclusions and our outlook in sections six and seven.

2 Literature Review

Smart services enable new business opportunities and revenue channels. Gavrilova and Kokoulina (2015) state out that the aim of smart services is the co-creation of value by consumers and smart services' providers. Thus, smart services are based on collaboration and customer interaction to gain value and are not only just consumed by customers (Baldoni et al. 2010; Demirkan et al. 2015; Beverungen et al. 2018). Machine intelligence and connected IS are required to enable value co-creation. Information and communication technology (ICT) must be used for smart services to be able to react to customer requirements and an individual customer context (Calza et al. 2015). Analyses using machine intelligence are based on data collection in real-time (Allmendinger and Lombreglia 2005). Several data sources and social contexts can be included for a single service (Lee et al. 2012; Alahmadi and Qureshi 2015). Then, data analysis tools and mechanisms are used to process this information to gain knowledge that can be used by smart services (Kynsiletho and Olsson 2012; Stoehr et al. 2018). Individual customer requirements are addressed, and quality of processes is improved through smart services (Massink et al. 2010). These aspects are summarized in the characteristics presented by Dreyer et al. (2019):

- Individual and highly dynamic service solutions
- Use of ICT and field intelligence
- (Real-time) analyses of technology, environment and social context data
- Value co-creation between customers and providers

Knowledge management is based on the identification and leveraging of knowledge in organizations to compete in the market (von Krogh 1998; Liu et al. 2017). It is embedded in KMS that "support creation, transfer, and application of knowledge in organizations" (Alavi and Leidner 2001, p. 107). This applies especially to knowledge-intensive processes (Massey et al. 2002; Sarnikar and Deokar 2017). Davenport and Prusak (1998) see three goals of knowledge management in organizations: visibility of knowledge, encourage knowledge sharing, and build an infrastructure for people to share knowledge. According to Fahey (2001) there are mainly three processes that are continuously repeated: new knowledge is discovered or created, the knowledge is shared between people and within the organization and is used then in daily work and for decision making. We see knowledge management in accordance with Fahey (2001) and Davenport and Prusak (1998) as a process from gaining or discovering knowledge, sharing knowledge to people and organizations and the facilitation of the usage of knowledge through organizational and technological mechanisms.

Knowledge is the basis to enable value co-creation between smart services' providers and customers in value networks (Payne et al. 2008; Bagheri et al. 2016). Knowledge management is inevitable because not only static, structured data is used to describe a customer's environment, but also highly dynamic and individual data (Lee et al. 2012). Knowledge management must be flexible and able to adapt itself to the context (Theocharis and Tsihrintzis 2013). Chatterjee and Armentano (2015) describe how to obtain intelligence from data. For smart services, an extension from an internal company knowledge management to a value network knowledge management must be performed (Bagheri et al. 2016; Stoehr et al. 2018). Therefore, an KMSSS architecture must be developed (Badii et al. 2017). A challenge is that knowledge integration from different sources must be ensured (Wang et al. 2011). To the best of our knowledge, there is no reference model existing so far connecting the design of KMS to smart services. This approach contributes to a better understanding of smart services both theoretically and in practice.

3 Research Design

Our research goals are to identify implicitly and explicitly named requirements for tailored KMSSS and to develop design principles and a KMSSS reference model. Therefore, we analyzed literature that deals with smart services, regardless of whether knowledge management is explicitly named. The requirements were extracted through a comprehensive analysis of the literature. In our research, these requirements are presented. Besides requirements that arise for knowledge management in general, there are also requirements specific for smart services. We developed a KMSSS reference model: the cubic model shows the variety of tailored KMSSS designs.

A comprehensive literature search was conducted to identify relevant literature in the field of smart services. It was oriented on the structured approach presented by Webster and Watson (2002). To ensure a rigorous literature search, both reliability and validity have to be guaranteed (Vom Brocke et al. 2009). Reliability refers to the precision of scientific research (Vom Brocke et al. 2009). In the context of our research, we documented the search process by describing the procedure including the used databases and search terms. Inclusion and exclusion criteria were specified to make the results of the literature search transparent. Validity was understood as the degree of accuracy. Referring to a literature search, it was the degree to which all relevant publications were found. We ensured validity by conducting a literature search in eight different databases: ACM, AISeL, Emerald Insight, IEEEXplore, InformsOnline, JSTOR, Science Direct, and SpringerLink. Additionally, we did not only search for articles containing the term “smart service”. Therefore, we were able to identify articles that consider services that are smart according to our understanding, but that do not use the term “smart service”. We predefined the three following search terms that were used for the search in the different databases: “smart service" OR "smart services", “digital service" OR "digital services", "electronic service" OR "electronic services" OR "e-service" OR "e-services". Moreover, both forward and backward searches were conducted.

To receive search results that focus on smart services, only the title and the abstract were considered where it was possible. After generating the search results, inclusion and exclusion criteria were defined to filter the results. First, all articles that were not written in English were excluded. We assumed that researchers write research articles of high quality in English to reach a global community. Second, non-academic literature was excluded, and not peer-reviewed papers were filtered out.

Our goal was to extract most of the relevant publications that deal with smart services. The characteristics presented in Chapter 2 were used to identify which articles of the remaining search results deal with smart services in our view. This resulted in a large reduction of possibly relevant articles because the second and third search terms, i.e. digital service and electronic service, often are not used as synonyms for smart services.

Both forward and backward searches were conducted as recommended by Webster and Watson (2002). In the forward search it was checked where the publications are cited. Within the backward search the citations of the relevant publications were reviewed to identify further relevant articles. Finally, 157 articles were considered in the following (a complete list of all articles can be found in the appendix).

All articles that were identified to be relevant were comprehensively reviewed. The whole texts were examined regarding requirements for knowledge management. Although knowledge or knowledge management often is not explicitly addressed, requirements are named implicitly when describing a service and its application. For example, it is emphasised that human-generated knowledge must be considered for decisions (Lee et al. 2015).

Characteristics are extracted that are not always applicable in the same way for different smart services, e.g., the necessary reaction speed. All identified aspects were classified in one of the following three categories: characteristics, capabilities, and technical functions. These categories were not predefined but developed during the review process. It turned out that all requirements that were named in the literature can be assigned to exactly one of the three categories. These formed the basis for our KMSSS reference model, developed with orientation on Becker and Delfmann (2007). The reference model shows the diversity of tailored KMSSS designs. The subsequent discussion includes implications for practitioners. Figure 1 summarizes our research design.

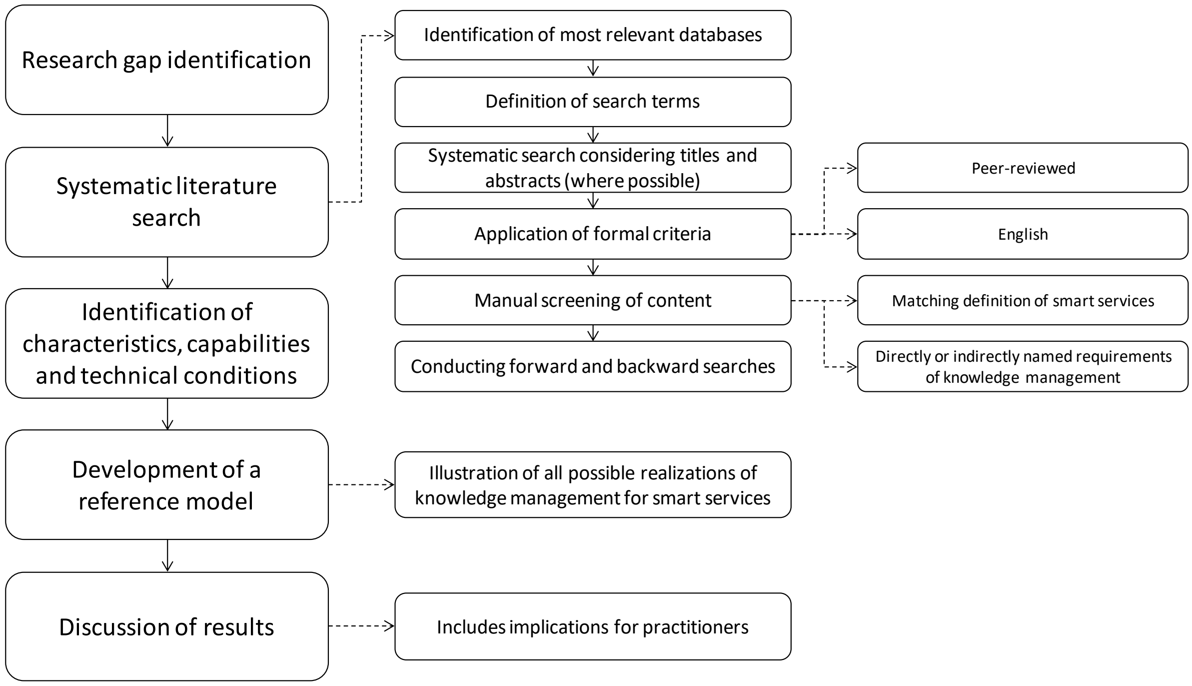

Figure 1: Research design

4 Tailored KMSSS

Although we limit our research to smart services, there is a wide range of diverse KMSSS designs. In the following, characteristics, capabilities and technical conditions extracted from the literature are presented. They are used subsequently to develop a KMSSS reference model, including all designs. A real-world example demonstrates why knowledge management is necessary for smart services.

4.1 Characteristics

When providing smart services, these are not realized by a single company. Usually, a value network is created to be able to provide and operate smart services successfully (Mathes et al. 2009; Tien 2012). As different participants of a value network are involved, KMSSS are complex compared to other applications (Bullinger et al. 2017). Additionally, not only the cross-company use is complex, but also the use within a company. Several different departments are participating with different interests and foci (Saunila et al. 2017). The more participants have access to the KMSSS, the more coordination effort is required (Tianyong et al. 2006).

Many different sources are used to realize a comprehensive and useful knowledge management (Perera et al. 2014; Korzun et al. 2015). One important source is the knowledge in the employees' heads (Barile and Polese 2010). Implementing this knowledge into the KMSSS requires suitable processes (Smirnov et al. 2015). The objective is that not only other employees can use the knowledge, but also machines (He et al. 2012). Depending on the smart services for which the knowledge is used, not only directly entered knowledge forms part of the KMS (Kynsilehto and Olsson 2011). Knowledge that is generated during smart services' operation must be included automatically, too (Mo et al. 2010).

Knowledge management is not static but dynamic (Yachir et al. 2009; Alti et al. 2015). Thus, knowledge is not only implemented once at the beginning. Knowledge management is living, and the content is changing and extended over time (Ren et al. 2014). An open KMSSS design contributes to living and always topical knowledge (Barile and Polese 2010; Anttiroiko et al. 2014). It is important that a certain quality is ensured (Fan et al. 2012; Mihovska et al. 2015). From a smart services' perspective, quality has an influence on the reuse of a service (Zo 2003). In connection with quality, transparency is important for useful knowledge management (Lesjak et al. 2014; Priller et al. 2014). As knowledge can be added and modified by several participants, mechanisms are required to track changes, too.

It is necessary that the knowledge management works efficiently (Yu 2004). For example, the storage of knowledge must be efficient since the amount of knowledge is growing over time. Efficient concepts and strategies must be implemented to store and manage knowledge efficiently (Al Nuaimi et al. 2015). Necessary knowledge must be extracted in a suitable time to be able to react to the current situation (Ciortea et al. 2016). Not only smart services as such are diverse, the contexts also are (Mo et al. 2010; Kwak et al. 2014). Smart services are characterized by the ability to be context-sensitive (Li et al. 2015; Seeliger et al. 2015; Wutzler et al. 2017). Technical, social and environmental information is considered to adapt smart services continually (Lee et al. 2012; Alahmadi and Qureshi 2015). It must be possible to use the same KMSSS in different contexts (Weijie et al. 2012).

Knowledge management enables access for different participants of a value network to the same knowledge base (Delfanti et al. 2015; Hussein et al. 2017). As smart services are characterized by value co-creation (Gavrilova and Kokoulina 2015), not only participants involved in the provision of smart services form part of the value network; smart services' customers also participate actively (Mikusz 2017). Thereby, information asymmetries between providers and customers are compensated (Dawid et al. 2016). But a challenge is that participants of a value network describe knowledge from a specific view (De Oliveira and Silva 2015). However, the knowledge should be useful for different participants and not only for the one who implemented it. This challenge also arises when modifying existing knowledge. Taking an algorithm to improve energy efficiency as an example (Byun and Park 2011), it must not be modified in a way that it is only more customer-centric for a single application, but less useful for all other ones. Nevertheless, it does not mean that domain-specific knowledge must not be part of the knowledge included in the KMSSS (Berna-Martinez et al. 2006). To sum up, the following KMSSS characteristics were identified (Table 1):

Table 1: Identified characteristics of KMS

Characteristic	General requirement	Smart service's requirement
Usage across departments	✓	✓
Usage in value networks		✓
Input sources are diverse	✓	✓
Usage by both people and machines		✓
Dynamic	✓	✓
Transparent	✓	✓
Applied in different contexts		✓
Standardized knowledge	✓	✓

4.2 Capabilities

Apart from characteristics of knowledge management there are also functional capabilities that must be ensured. Knowledge management is characterized by a collection of knowledge. Many types of knowledge must be integrable (Li et al. 2015; Badii et al. 2017). Knowledge does not only include information in form of texts but also, e.g., algorithms, rules, methods and optimization models (e.g., Maleshkova et al. 2016). Existing knowledge must be combinable with new knowledge (Kim et al. 2015) to continually improve and expand the knowledge base. The mentioned new knowledge can be entered directly (Westwood and Cazier 2016), e.g., by employees, or extracted automatically using various techniques.

Smart services often operate in real-time (Tien 2012; Mukudu et al. 2016; Huang 2017) which is why the KMSSS must work in a performant way (Mihovska et al. 2015). As many different types of smart services are possible or already existing (Delfanti et al. 2015), the dynamics of knowledge management differ. This concerns the rate of change of knowledge. Additionally, the necessary deployment speed varies. Usually, the higher the speed, the higher costs occur. Therefore, it must be determined which speeds are required for respective smart services and connected customers (Kwak et al. 2014).

Classifications of knowledge contribute to realize efficiency (Byun and Park 2011; Chatterjee and Armentano 2015). Depending on the provided smart services, the most suitable classification changes (Alti et al. 2015). For example, it is possible to separate mathematical models from further knowledge. The idea is that knowledge can be provided faster when only the respective class of knowledge is considered. The KMSSS should be able to identify redundant information (Alti et al. 2015). This provides several advantages. On the one hand, possible inconsistencies are avoided and storage space is saved. On the other hand, the knowledge management works more efficiently. The KMSSS must be able to check carefully if there are duplicates (Wang et al. 2011).

Smart services are context-aware services (Mo et al. 2010). Depending on the respective context, e.g., customer-centric recommendations from the KMSSS differ (Yachir et al. 2009; Wünderlich et al. 2012). The challenge is that contexts can be diverse and each context is individual (Mikusz 2017). To meet this challenge, the KMSSS has to generalize context information to be able to react adequately. An important function of a KMSSS is that it can build relationships between different information and knowledge (Barile and Polese 2010; Chu and Lin 2011). Therefore, new knowledge can be generated without new input (Al Nuaimi et al. 2015). But it must also be possible that knowledge is adapted manually (Westwood and Cazier 2016). A KMSSS must support both ways to generate new knowledge and thereby to improve the connected smart services. Protocols that register all activities in the KMSSS contribute to transparency (Chu and Lin 2011). In this case, security and privacy concerns are important challenges of KMS (Strüker and Kerschbaum 2012; Ye and Qian 2017). Not all knowledge that is stored in the KMSSS should be available for all participants. Therefore, role-based authentication is necessary. Only knowledge should be accessible that is relevant for the respective user. Due to this, a flood of information and knowledge is avoided, too. Additionally, the more users have access and modification rights for a specific area of a KMSSS, the higher is the risk of falsification of knowledge.

The KMSSS must be able to output adequate knowledge in a structured way (Chu and Lin 2011). This refers to the amount of knowledge and the depth. For example, when smart services are implemented for the first time at a customer's location, the main functionalities concerning the respective smart services have to be ensured. In the later operation phase, more specific knowledge is required to adjust smart services and their contributions efficiently. As the required knowledge depth and diversity is not entered directly, functions are necessary to identify it. Knowledge that was used once must be accessible for future use (Martin et al. 2014). Therefore, knowledge management must be well structured (Wang et al. 2011). As the knowledge must be readable and usable by all participants of the value network, their devices and connected IS, standardization is necessary (Ma et al. 2010).

The collected and processed knowledge is not only used for display purposes, but in the smart services' context it is used within processes (He et al. 2012). For example, knowledge is used for decision support (Tien 2012; Gretzel et al. 2015). In order to make the best decision, a structured and reliable knowledge management is required that works efficiently. This refers to both proactive activities and requests. It implies that a KMSSS triggers with or without manual intervention (Jerald et al. 2016). Table 2 sums up the identified KMSSS capabilities.

Table 2: Identified functional capabilities of KMS

Functional capability	General requirement	Smart service's requirement
Integrability of many types of knowledge	✓	✓
Combining knowledge	✓	✓
Generating knowledge automatically		✓
Reaction in real-time		✓
Efficient storage	✓	✓
Efficient management	✓	✓
Avoiding redundant knowledge	✓	✓
Generalizing context information		✓
Meeting security and privacy concerns	✓	✓
Situation-sensitive output		✓
Standardizing knowledge	✓	✓
Reliability and robustness	✓	✓

4.3 Technical Conditions

A KMSSS is not isolated, but interacts with other tools and applications (Allmendinger and Lombreglia 2005). For example, tools for decision support must be considered and implemented in the network for smart services (Tien 2012; Gretzel et al. 2015) and interfaces must be provided (Bedogni et al. 2013). Not only technical interfaces between devices and other tools must be considered, but also a user interface must exist (Baldoni et al. 2010). Through a user interface, employees are able to extend the knowledge base and make individual knowledge accessible for other employees and participants of the value network as well as usable for devices and other IS.

Knowledge management has to be integrated in the technical smart services' concept and strategy. This can be realized due to integrating the KMS in a middleware (Wutzler et al. 2017). This implies that different sources are not directly connected. Data and information from different sources can be synchronized (Allmendinger and Lombreglia 2005). There are multiple possibilities to implement a middleware (Pereira et al. 2018). Database management systems need to be used to combine knowledge from different databases and to establish connections to different IS. Different types of databases exist for specific knowledge, e.g., multimedia databases (Alavi and Leidner 2001). Company information can also be stored on Internet or intranet sites to be easily accessible (Alavi and Leidner 2001). Depending on structure and amount of knowledge, memory and process speeds are factors that must be considered. Based on these database technologies, methods such as error analysis, machine learning and knowledge discovery can be realized (Liao 2003).

Employees must have the possibility to maintain the knowledge base manually (Westwood and Cazier 2016). Concepts and strategies how to realize this, e.g., generating reports of all activities or integrating feedback functions, must be implemented to ensure transparency (Chu and Lin 2011; Li et al. 2015). Not only concepts and strategies for role-based authentication have to be developed, but these must also be implemented as part of the KMSSS (Wutzler et al. 2017). For one thing, the KMSSS must be secure. Otherwise, access must be simple to be able to react quickly (Mathes et al. 2009; Holgado and Macchi 2014). A summary of the identified KMSSS technical conditions can be found in Table 3.

Table 3: Identified technical conditions of KMS

Technical condition	General requirement	Smart service's requirement
Interfaces to other tools and IS		✓
User interface	✓	✓
Integrability in a middleware		✓
Role-based authentication		✓

4.4 Reference Model

The analyzed requirements that are not the same for diverse types of smart services are taken to describe a KMSSS reference model. It displays diverse designs of tailored KMSSS. It is realized with a cube and has three dimensions: input/output, structure and reliability (Figure 2).

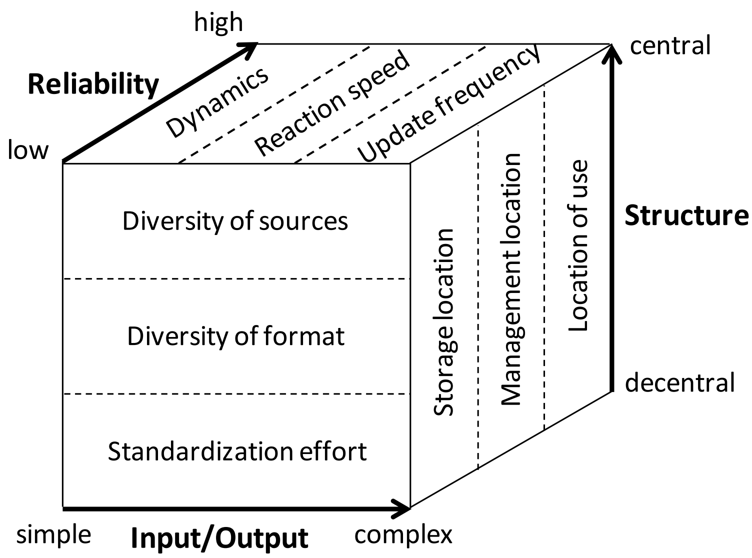

Figure 2: KMSSS reference model

The first dimension concerns the input as well as the output. Knowledge management can only exist with input from which knowledge is generated (Al Nuaimi et al. 2015). The knowledge comes from diverse sources (Delfanti et al. 2015). The more sources are considered the more complex is the KMSSS. Thereby, many different types of knowledge are possible (Cellary 2013). Relatively simple forms are text information. But there are also many different further types of knowledge possible, such as mathematical models or algorithms (Keskin and Kennedy 2015). The input can be structured or unstructured. Additionally, standardization was already discussed in the context of knowledge for smart services (e.g., Berna-Martinez et al. 2006). Depending on the smart services it can be easy to standardize the necessary knowledge. This supports fast searches and simplifies the storage and processing of knowledge. Furthermore, it is readable by different devices and usable by several tools (Ciortea et al. 2016). It is also possible that standardization requires huge effort (Tianyong et al. 2006). The mentioned input is not necessarily direct input but can also be indirect, i.e., new knowledge is generated from operating smart services (Cellary 2013). Similar to the input, the forms of output are diverse and vary from relatively simple to complex. This depends on the smart services for which the KMSSS serves.

Structure is the second dimension of the reference model. It includes diverse aspects regarding local conditions. The first one is local or public knowledge storage (Fan et al. 2016). Implementations between these two are also possible. As different participants of a value network use the same KMSSS, the location regarding the storage is important (Ferretti and Angelo 2016). Usually, there is knowledge that is relevant for all or most participants (Töytäri et al. 2017), e.g., the topology of a production machine when smart services are offered for failure detection. This knowledge can be stored globally. But there is also knowledge that is specific or sensible. For this type of knowledge, it is recommended to store it locally. Depending on the provided smart services a storage concept and strategy must be developed. The same applies for the management. It is possible to have a KMSSS that is managed centrally for the different participants (Ferretti and Angelo 2016). But it is also possible that the participants maintain their knowledge on their own. If the knowledge is stored and managed centrally, it is useful to also use the knowledge centrally. For example, this means that models or decision support systems (DSS) are executed in a cloud and not on a local server. Security and performance issues have to be considered when designing the structure of the KMSSS.

Reliability is the third dimension that is considered within the cube. Smart services are dynamic (Batubara 2015). As knowledge management supports or even enables smart services, it must be equally dynamic. Knowledge management only works reliably when this is ensured. Coming from the provided smart service, the speed in which action is required differs. Partially, very quick reactions are necessary (Holgado and Macchi 2014), e.g., to avoid a machine downtime. In other cases, e.g., process optimization, the high speed is not necessary. Depending on the type of knowledge, update cycles differ (Strüker and Kerschbaum 2012). In some cases it is inevitable to update the knowledge immediately. In other cases it is sufficient to do so in determined periods. Holding the reliability of knowledge management as high as possible seems to be the best solution at first sight. But it must be considered that high costs are related to that.

Table 4: Three dimensions and aspects of the KMSSS reference model

Dimension	Aspect	Description
Input/output	Diversity of sources	The more sources are considered to gain knowledge, the more complex is the KMSSS.
	Diversity of format	Knowledge has many different formats and can be unstructured or structured.
	Standardization effort	Effort to standardize knowledge is related to the complexity of the input and output as well as the related smart services.
Structure	Storage location	Knowledge can be stored locally at a server of a value network participant or centrally, e.g., in a cloud.
	Management location	Responsibility for the KMSSS can be concentrated or distributed over the value network participants.
	Location of use	Methods, models or further knowledge can be used centrally, e.g., in a cloud, or copied and stored locally for further use.
Reliability	Dynamics	The more dynamic smart services are the higher are the requirements for the KMSSS dynamics.
	Reaction speed	Smart services can make real-time reactions necessary which is why the KMSSS often must react quickly.
	Update frequency	The higher the demands regarding reliability of the KMSSS are the higher is the update frequency.

Each point of the cube depicted in the developed reference model is one design of a tailored KMSSS. Depending on the provided smart services the most suitable design of a tailored KMSSS differs. Table 4 summarizes the aspects that are considered when looking at the dimensions of the cubic reference model.

4.5 Applicability Check

The following real-world example demonstrates how a KMSSS can be used in industrial companies to improve processes, offer services and to gain value. We focus on a value network consisting of component supplier, machine builder and machine operator in the industrial sector. Predictive maintenance as a smart service helps machine operators to keep machines' availability high and to reduce the risk of machine breakdowns.

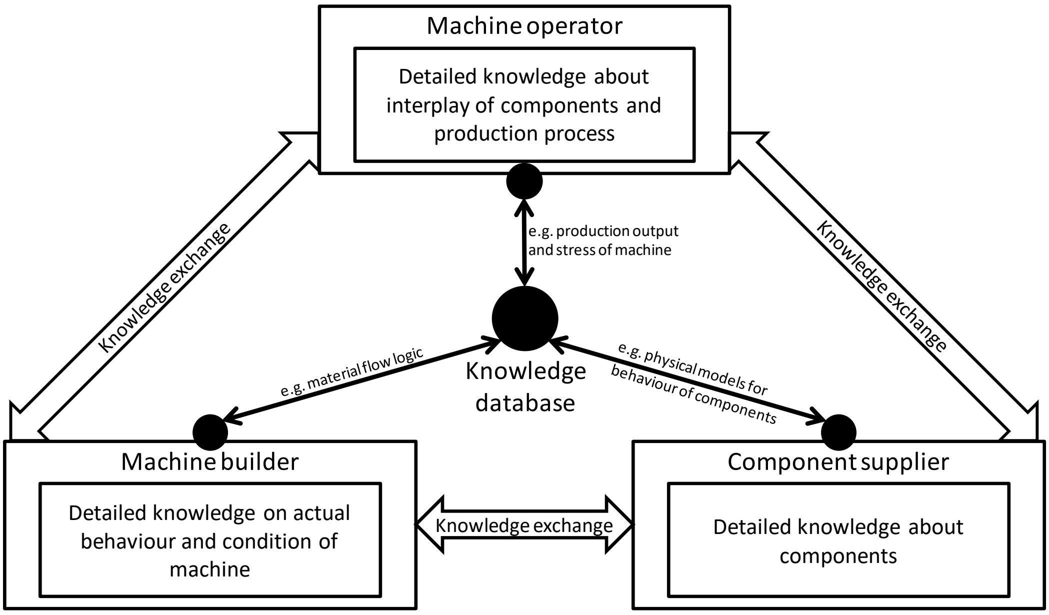

Figure 3: Exemplary knowledge flow in a value network for predictive maintenance activities

An overview about the real-world example for the presented value network can be found in Figure 3. Each participant of the value network has the best knowledge about its own components, machines or processes. With the help of a tailored KMSSS this knowledge can be combined and additional knowledge can be generated. All partners benefit from knowledge exchange and are therefore willing to share their domain knowledge. During machine operation, sensor data provide the current state of a machine or production process. Data analysis of these sensor data must be combined with individual knowledge of the specific machine or the current production process. Knowledge about the machine is provided by the machine builders, having detailed knowledge about the interplay of components, machine functions and machine structure. When a component problem is identified, machine operators and machine builders presumably have no detailed knowledge about the individual component. The component supplier has better possibilities to detect anomalies or failures when knowledge about the production processes or individual applications of the machine is provided. As knowledge used for the explained smart service often is a company secret, a KMSSS structure primarily local is useful. Another argument for a decentralized structure is that knowledge is very specific which is why it can only be maintained by the participant that provided it. In case an external provider is responsible for maintaining the KMSSS a central structure would be required.

Predictive maintenance raises the question when a machine should be maintained and which spare parts are needed therefore. Prediction models based on the previously described knowledge enable to predict when maintenance must be performed. This maintenance should be performed based on current usage of the machine and not according to fixed maintenance schedules. Production planning requirements must be considered to find the best time frame between probability of breakdown and cost for a machine downtime. The reliability does not necessarily have to be very high for this part of the predictive maintenance service because an adaption in real-time is not required. The maintenance scheduling should be adapted within hours, but an extreme high availability of the KMSSS is not required. If the focus of predictive maintenance is not only to plan maintenance activities but also to avoid failure, reactions within minutes might be necessary. In this case, a high reliability and availability of the KMSSS is required.

Machine builders and component suppliers have various customers. Comparing machine operations of different customers shows anomalies of specific customers. Also, the comparison of different production plants shows anomalies. With the help of this, knowledge specific actions can be taken, and machine availability can be ensured. It must be guaranteed hereby that data is anonymized and not shared with unauthorized companies. Input and output are more complex than in the case of smart services where common knowledge is used and adapted.

5 Results, Discussion, Implications and Recommendations

In the literature, knowledge is emphasized to be very important for successful smart services (Wang et al. 2011). A reliable knowledge management enables to continually improve provided smart services. As a characteristic of smart services is that they are individually and continually adapted, knowledge is necessary (Li et al. 2015). For example, sensor data as such are not valuable. Interpreting this data and transforming it into information generates value. A tailored KMSSS is not a rigid IS, but underlies a continual transformation. New knowledge is added, existing knowledge is substantiated, or redundant knowledge is consolidated. Although it is possible to automate these processes partially, it is necessary that the people that form part of the value network of smart services also form an active part of the tailored KMSSS. Often, knowledge only exists in the heads of the employees. To be able to provide smart services on the long term, it is necessary that knowledge is stored and subsequently provided systematically. Both other participants of the value network and machines need to be able to read and use the knowledge. Standardization helps to achieve this. But tailored KMSSS must be flexible to be customer-centric. Therefore, a balance must be found between standardization and flexibility. This is reflected in the input/output dimension of the developed reference model. The individual context must be considered to provide adequate output and the KMSSS should be able to react to changing circumstances. Thereby it must be considered that smart services partially require reactions in real-time. A standardized and efficiently working KMSSS is required to enable it.

Participants of the value network are different companies and customers. Not all knowledge in the KMSSS is intended for all participants. It includes internal knowledge such as algorithms or mathematical models. Furthermore, not all knowledge is relevant for all participants. To avoid a flood of data, a suitable concept and a strategy of how to manage data and knowledge streams is inevitable. Interfaces to other IS and tools are advantageous. In this context, security and privacy concerns arise. This does not only affect processes, but also the technical infrastructure. If there is already an infrastructure existing, the KMSSS has to be embedded adequately. This is important for the reliability dimension of the presented reference model. Role-based authentication is helpful for efficient knowledge management. The roles can differ across the participants of the value network, across employees in the same company, and even across employees of the same department. But, role-based authentication is not the only possibility when thinking about controlled access to knowledge. It is also possible not to centrally store the whole knowledge. It is possible that some participants have not only access to a central KMSSS, but also own local ones. This is represented by the structure dimension of the reference model. Depending on the type of knowledge the participant who stores the knowledge can give access to other participants. It can result in a KMSSS that is partially public and partially local. This has effects on the administration. Such a KMSSS cannot be managed centrally, but the various providers of knowledge must maintain their part of the KMSSS. As smart services are not locally based but are provided globally, remote access is inevitable. For example, tunnel services can be implemented. Table 5 presents recommendations for tailored KMSSS design that result from the discussion and considered implications.

Table 5: Recommendations for KMSSS design

Recommendation	Comment on the application
Automated knowledge generation	The KMSSS must be a living IS. New knowledge from operating smart services should be integrated automatically and information should be combined to generate knowledge.
Machine readability	Knowledge must be understandable both by people and machines what requires standardization.
Context sensitivity	Smart services are context sensitive as individual requirements are satisfied: knowledge management must contribute to that.
Use context information	Specific context information should be abstracted for knowledge management support.
Real-time reaction	For smart services, reaction in real-time is partially necessary: a KMSSS must enable and support that.
Individual output	Depending on the smart service, context and requirements help to adapt output individually.
Value network	Knowledge is not only used across departments but also across participants of a value network.
Interfaces	The KMSSS should be connectable to other IS and tools.
Integrability	The KMSSS should be embedded adequately in existing IS and processes.
Security and privacy	Measures such as role-based authentication address security and privacy concerns; concepts and strategies for remote access are inevitable.

It is recommended that a KMSSS is not only used but that it is also reflected whether the KMSSS is still suitable for the offered smart services. Knowledge management is not only a topic in the operating level, but also in the management and strategic levels. Independent from the specific application of knowledge management it is highly important that it is oriented on the provided smart services and their customers.

The presented demonstration example shows that a tailored KMSSS is the prerequisite for offering smart maintenance services in the context of industrial applications. Different knowledge sources within a company as well as in the value network need to be considered and combined. It also shows that such smart services cannot be provided by a single partner but through interactions of the participants of a value network.

6 Limitations

We did not only search for publications dealing with smart services but also for ones that deal with digital services and electronic services. The second and third search terms were chosen because we assumed that, especially in earlier publications, it is already dealt with services according to the presented definition.

Nevertheless, it cannot be excluded that there are further search terms that partially also describe services that are smart in our understanding. Another point of the structured literature review is the considered databases. We assumed the eight chosen databases to be the most important ones in the field of IS Research (ISR). Although we found very relevant publications in these databases, it cannot be excluded that there are relevant articles in other databases. We decided whether a publication is relevant for our research or not, using characteristics presented at the beginning. From our point of view, it contains the relevant aspects of a smart service. Nevertheless, another definition might have led to another literature basis from which the reference model is derived.

Characteristics, key capabilities and technical conditions formed the basis for the developed reference model. A theoretic approach was taken to look at tailored KMSSS. As smart services are not only theoretic constructions but are also highly relevant in practice, interviews with experts can add additional aspects that are not yet considered. The cubic model was developed subsequently from requirements.

7 Conclusions and Outlook

We looked at knowledge management from a smart services' perspective. Publications that considered smart services were comprehensively reviewed to identify requirements for knowledge management. To ensure that the requirements named in the literature were identified in our research, a structured literature review was conducted.

Characteristics, capabilities and technical conditions of tailored KMSSS were identified. This kind of knowledge management differs because smart services are embedded in value networks. Usually, not a single company offers a smart service, but different participants are involved. Customers also form part of the value network because smart services are characterized by value co-creation. Participants can be located all over the world. Therefore, a KMSSS is not a local IS but globally used. Additionally, smart services often require actions in real-time or near real-time. Specific requirements regarding reliability arise from that. The possible input is manifold because smart services are manifold, too. Taking all aspects into account illustrates the complexity of a tailored KMSSS.

As smart services are a relatively new research field, there are only few best practice studies. The role of knowledge management within the field of smart services may change. Further research in this field is important for the development of this topic. As we focused on the design of tailored KMSSS, further approaches are interesting concerning technical realizations. How to embed new requirements in existing KMSSS is interesting for those who already use such IS.

A KMSSS must be a learning IS and continually be improved. It must not be a static IS, but a dynamic and living one. Knowledge management leads to improvements of provided smart services or even enables them. Additionally, processes between participants of the value network and inside a company are improved. As smart services are diverse, there is not the only one KMSSS that fits best for all types of smart services. Many different specifications exist for knowledge management characteristics. The reference model developed in our research illustrates the diversity of designs for tailored KMSSS. The recommendations derived from the comprehensive review emphasize the importance of the topic in practice.

Appendix (List of all 157 publications included in the literature review)

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