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

Der Wirtschaftswissenschaftlichen Fakultät der

Gottfried Wilhelm Leibniz Universität Hannover

zur Erlangung des akademischen Grades

Doktorin der Wirtschaftswissenschaften

– Doctor rerum politicarum –

vorgelegte Dissertation

von

Sonja Dreyer, M.Sc.

[redacted]

2019

Betreuer und Gutachter:	Prof. Dr. Michael H. Breitner
Weitere Gutachterin:	Prof. Dr.-Ing. Astrid Nieße
Vorsitzende der Prüfungskommission:	Prof. Dr. Annika Herr
Weiteres Mitglied (beratend):	Dr. Ute Lohse

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.

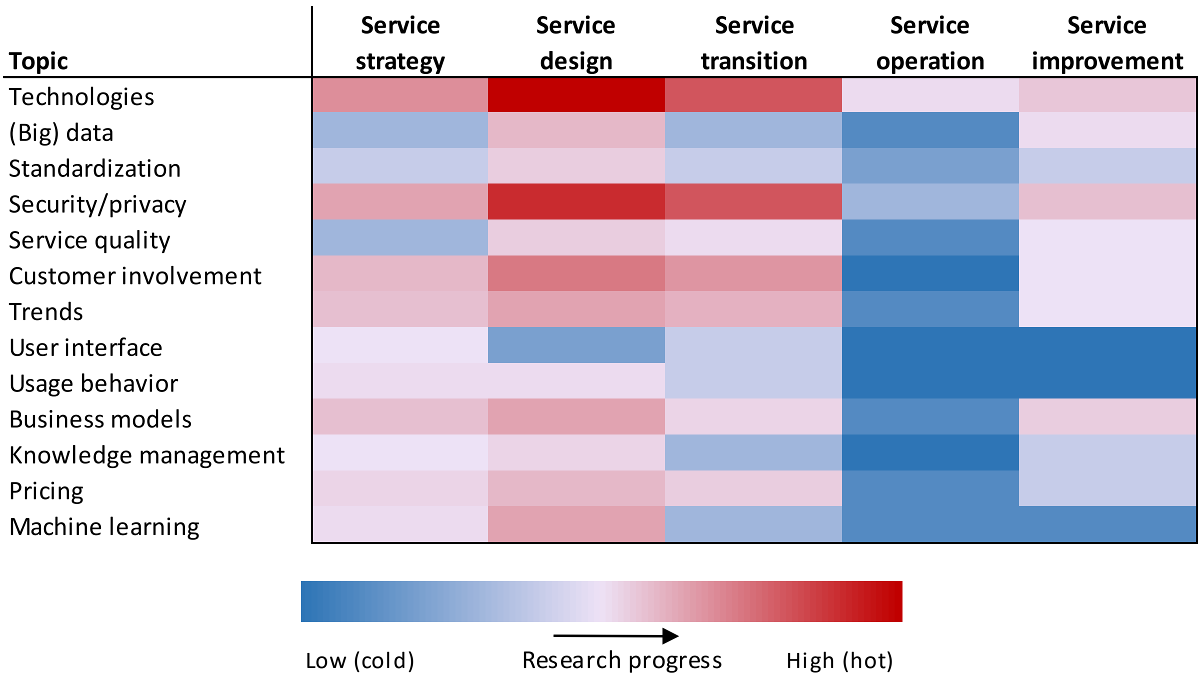

Figure 1. Heat map summarizing the research intensity

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.

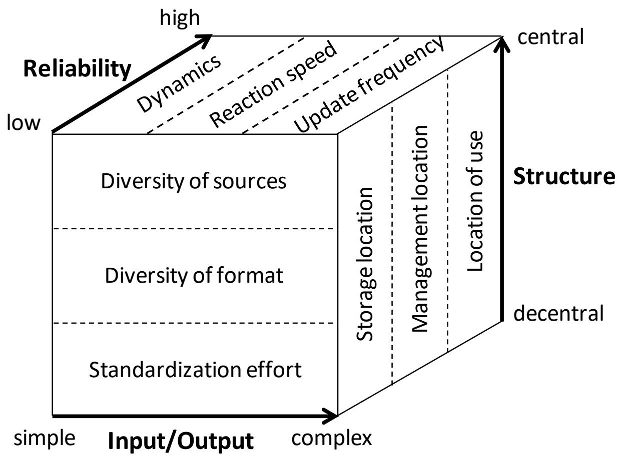

Figure 2. Cube model illustrating the diversity of knowledge management for smart services.

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.

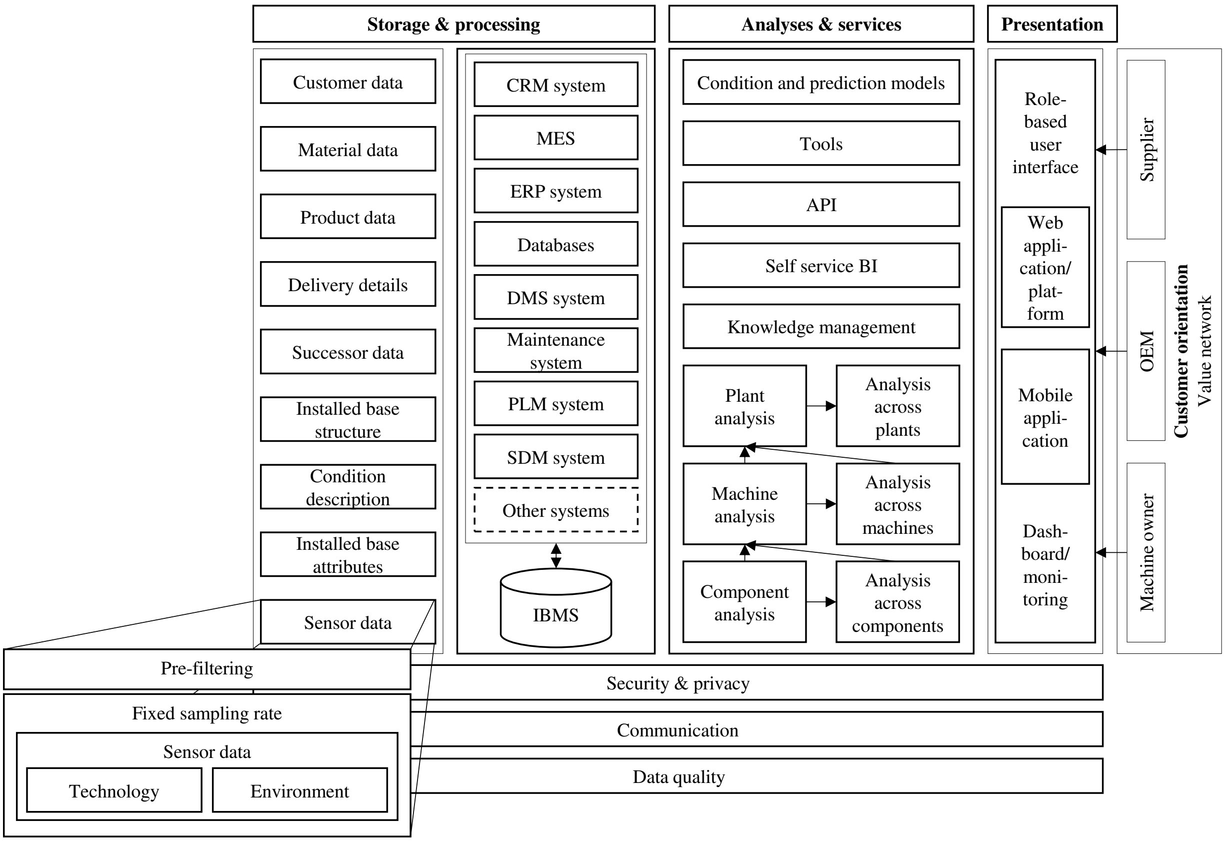

Figure 3. Integrated installed base management system

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.

Table of Contents