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

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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.

Keywords: Digital twin, information architecture, installed base management, smart services, product-service system

1 Introduction

In manufacturing industry, machinery and equipment are subject to high demands on availability and productivity [1], [2]. To meet these requirements, original equipment manufacturers (OEMs) as well as machine component suppliers shift in emphasis from selling only technical products to offering additional individualized smart services [3], comprising e. g. maintenance, repair, spare parts delivery, process consulting. Services are an economic guiding force for OEMs and machine component suppliers [4] because the supply of services in addition to products leads to new sales opportunities and to greater customer loyalty [5-7].

When considering individualized smart services, a major challenge for OEMs and machine component suppliers is that they often lack knowledge about the state of the machinery and equipment during the use phase [1]. Therefore, the collection and processing of condition monitoring data (field data) has been discussed within academic literature as inevitable for offering guaranteed machinery and equipment availability and productivity [8], [9]. However, the integration of condition monitoring

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data with installed base data (i.e. product master data, service data and contractual data [10]) is a necessary precondition for the provision of individualized smart services that has been rarely recognized by researchers. Organizations in value networks (i.e. OEMs, machine component suppliers and machine owners/operators) face the problem of how to use existing data from IT systems (e. g. ERP, MES, CRM) to depict machines with the respective installed components, locations, maintenance protocols etc. and how to enrich them with real-time data. Creating a digital twin based on these data provides the basis for rendering individualized smart services in value networks. Digital twins are realistic models representing machines with all their components, their current state as well as their interaction with the environment [11], [12]. Therefore, a digital twin is not static but dynamic which is why a standardized and consistent data and information management is necessary [13]. Although researchers began to work out information sources for installed base characterization [14], a generalized information architecture for installed base management that aims to enable smart services is still missing. An information architecture enables to store and process data, to analyze and evaluate them and to use them to offer services. Therefore we proposed the following research question:

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

To answer this research question and to build a bridge between academic rigor and practical relevance, we adapted the action design research (ADR) approach [15] in the context of an international engineering and manufacturing company. With the use of different cycles, ADR allows continuous interaction between researchers and practitioners in early stages.

The remainder of this article is structured as follows: Section 2 introduces the action design research approach and its application. The information architecture is designed in section 3, including a literature review in the field of installed base management. General design principles are carried out and results are discussed in chapter 4. The article ends with limitations and conclusions in sections 5 and 6.

2 Research Design

Starting from existing work in the research field of installed base management, the aim of this study was to develop an information architecture for practitioners to enable individualized smart services. Additionally, design principles of an information architecture for installed base management that can be applied within multiple companies were developed as theoretical contribution. For this purpose, the action design research (ADR) approach by Sein et al. [15] was selected as the underlying research methodology. Motivated by an increasing debate about the gap between organizational relevance and methodological rigor [16], [17] in IS research, ADR was developed in order to close this gap by presenting an integrative research approach of action research and design research [15]. ADR is well suited for deriving generally applicable knowledge while incorporating two main challenges. First, in order to generate practically relevant outcomes, ADR aims to solve a problem in an organizational setting by facilitating ongoing interaction of researchers and practitioners. Second, in order to account for academic rigor, ADR develops generalized design principles that address a class of problems through formalized learning from organizational intervention (Figure 1).

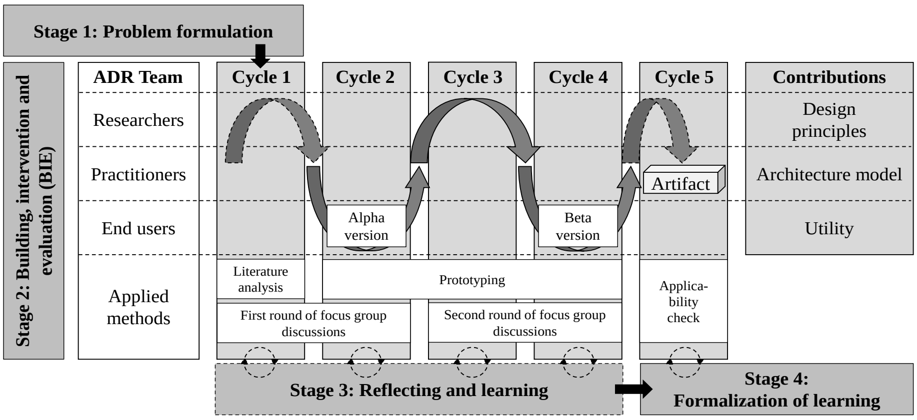

Figure 1. Research design based on the ADR approach from Sein et al. [15]

In the context of this study, the first stage was driven by a problem perceived at an international engineering and manufacturing company. In order to offer individual smart services in the area of installed base management, the target company required an information architecture to be able to organize and analyze machine owner's installed base data. In stage one the specific practical problem was formulated as an instance of a broader class of problems. An ADR team was formed, made up 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. The shared competencies facilitated the problem definition and formulation. In the building, intervention and evaluation (BIE) stage, five iterative cycles were carried out in order to build and continuously evaluate a prototype for an information architecture for installed base management. In the first cycle of the BIE stage, an initial prototype ('Alpha version') was derived from requirements analysis that was conducted during the problem formulation stage, as well as analysis of existing literature and a series of focus group discussions involving practitioners and end users. Subsequently, the alpha version was presented to practitioners and end users for evaluation by conducting a second series of focus group discussions in cycle two. Each focus group discussion was documented and qualitatively evaluated afterwards [18]. Based on the feedback gathered in the previous cycle, the prototype was further improved and specified ('Beta version') in cycle three. The applicability of the proposed information architecture was assessed during a test run with real data from a customer organization in cycle four. For the purpose of evaluation, next to end users, members of the target company's service product management, service account management, IT application development and IT strategy departments were involved. Feedback was used for incremental reshaping of the prototype in cycle five until the final version was reached. For continuous evaluation of each development step of the proposed information architecture, stage three (reflection and learning) was carried out simultaneously to the BIE stage. This procedure allowed a better understanding of the problem from different points of view. In stage four, learning from the specific solution was generalized in order to address a broader class of problems. Hence, the developed information architecture aims for general applicability for various companies and is not limited to the use case of the target organization. The development of design principles contributes to this.

3 Information Architecture Development

3.1 Problem Formulation

The presented information architecture emerged from a project of an international engineering and manufacturing company for storing and structuring machine owner's installed base data. Agile project management was used to realize the project what is appropriate to the ADR approach. The executing company operates in 60 countries and has the headquarters in Germany. The project concerned a service where machine and component data of a customer's machine are collected and structured subsequently. A detailed overview of the built-in components and its condition is given through creating a digital twin. This provides the basis to offer individualized smart services.

A use case was defined as an example for smart services in the manufacturing industry which are basing on installed base management. The examples arose from focus group discussions with employees of a large German automotive manufacturer, a machine owner. The participants of the focus group discussion came from the departments of maintenance processes, systems technology and automation technology. Additionally, practitioners from the engineering and manufacturing company, a component supplier, formed part of the group. They mainly came from the IT and the services department. The discussion dealt with services that would help to simplify tasks related to asset management. Mainly, there were six key questions the participants of the focus group discussion have which are not answered until now.

Table 1. Key questions of a machine owner regarding installed base management

Key question
How can installation errors be avoided?
How can error causes be identified immediately and reliably?
How can maintenance efforts be minimized?
How can maintenance schedules be planned optimally?
How can we learn from experiences?
How can knowledge be provided at the right time and at the right place?

All the questions, shown in Table 1, were answered within a use case for smart services. The use case as an example for smart services contributes to specify the information architecture for installed base management. The idea of the use case was to use sensor data and to connect them with further installed base data to identify the current state of the machine as well as of the integrated components. When knowing exactly for what kind of task the components are used analyses enable to identify error causes immediately and reliably. During the production, it does not only have to be looked at a single machine but the context of all machines in a production line is important. For example, on the basis of digital twins maintenance schedules can be optimized. This includes systematic maintenance as well as predictive maintenance depending on the analyses results of the data. Such a smart service would help the maintenance department to ensure a high availability of the machines. Additionally, an integrated visualization cockpit enables to support the machine operator. In case of an error the machine operator receives concrete instructions what has to be done to solve the problem. This requires that a history of former errors, the respective error code and solutions exist. In a first step, an information architecture was necessary to be able to structure, standardize and analyze installed base data. Requirements for the architecture were determined in several focus group discussions as well as from existing literature.

3.2 Related Literature

According to the first cycle of ADR, a comprehensive literature review was conducted [19] to identify and analyze the current state of research in the area of installed base management and digital twins. A list of search terms was predefined and it was mainly searched through seven databases: AISeL, IEEExplore, JSTOR, ResearchGate, Science Direct, SpringerLink, Taylor & Francis.

Table 2. Number of hits for different search terms

Search term	*Hits*	*Temporal and thematic restriction*	*Relevant title and abstract*	*Strong relation to research topic*
“installed base management“	84	22		
“asset management”	20389	1042		
“inventory management”	4090	706		
“inventory data”	14957	382		
“asset data”	1715	585	92	26
“machine data”	3645	711		
“installed base data”	25	24		
“digital twin”	53	53		
“digital shadow”	71	71		

As there were many hits due to the search terms (Table 2), the hits were temporally restricted. Publications older than 1995 were excluded. Furthermore thematically restrictions were made and only publications in journals and proceedings in fields related to information systems were included. The identified articles were checked for general relevance for the research topic by title and abstract. Afterwards the remaining publications were examined regarding their contribution to at least one of six categories developed (Table 3) by considering the whole article. The term installed base management is rarely discussed in academic literature. Asset management has a close relation to installed base management which is why this is also part of the literature review. According to Lin et al. [8] the objective of asset management is to support and optimize the lifecycle of physical assets. As an extension to asset management, in installed base management the individual components of the machines and their interplay within the machine and across them are also in focus. Installed base management goes deeper into the machines to ensure a high machine availability. But in contrast to installed base management asset management has found plenty of recognition by researchers.

Table 3. Literature categorized by focus

Author(s)	*Data sources*	*Data quality*	*Using large datasets*	*Digital twin*	*Information architecture*	*Services*
Abramovici et al. 2016 [27]	●	●		●		○
Bahga, Madisetti 2012 [25]			●		○	
Borchers, Karandikar 2006 [14]	●	●				○
Cai, Ziad 2003 [23]	○	●	○			
Felden, Buder 2011 [35]	●	○			●	
Furtak et al. 2015 [26]		●	●			●
Jun, Fang 2013 [36]		○		●		
Gabor et al. 2016 [12]	○			●	●	●
Lee et al. 2013 [13]			●	●	●	○
Lim et al. 2015 [37]						●
Luoto 2013 [21]	○	●				
Mert et al. 2016 [1]						●
Mohseni 2003 [30]	○				○	●
Mueller et al. 2003 [32]					●	
Narayanamurthy, Arora 2008 [38]					●	○
Neely 2008 [29]						●
Neff et al. 2012 [31]					○	●
Power 2014 [24]	●		●			
Rosen et al. 2015 [11]	●			●		○
Sarfi et al. 2012 [22]	○	●	○			●
Thies, Stanoevska-Slabeva 2011 [39]	○	●			●	●
Turunen, Toivonen 2011 [20]	●					●
Wollschlaeger et al. 2015 [33]	●				●	
Zampou et al. 2015 [34]	●	●			●	
Ziekow et al. 2010 [40]	○				●	
Zolnowski et al. 2011 [28]						●

● Considered topic ○ Partially considered topic

Borchers et al. [14] outlined that the sources of installed base data are manifold. Sales and enterprise resource planning (ERP) systems, production databases and service information systems are the sources mentioned by the authors. Turunen et al. [20] supplemented this list and indicated that field technicians and other operational staff are an important channel for additional information. Louto [21] agreed and noted that manually collected data plays a decisive role when executing services. Sarfi et al. [22] consider data quality as an important aspect in the field of asset management. Cai et al. [23] looked more closely at the completeness of the data as part of data quality and proposed a method for evaluating it. Because a huge amount of data is required to maintain a good record, Power [24] described how to use semi-structured and unstructured large datasets for analytics. Although the author emphasized machine data as a main contributor to adding value, the article gives a more general overview of the topic of large datasets. Bahga et al. [25] looked especially at machine data and how to analyze it. But in their article, machine data is put on a level with sensor data. The concentration on sensor technology is pursued by Furtak et al. [26]. Creating a digital twin, also named as digital shadow, is rarely considered in academic literature. Abramovici et al. 2016 [27] define digital twins as virtual smart products. Gabor et al. [12] see digital twins as the basis for further applications. Rosen et al. 2015 [11] agree to that and discuss the importance of digital twins for autonomous systems in manufacturing. They summarized that digital twins are important in the whole lifecycle of a product [11]. As there is no additional value unless the data is used to generate new services, the service aspect is subject of discussion in several publications. Services based on remote technology is covered by Zolnowski et al. [28]. Neely [29] agreed that collecting data and analyzing it forms the basis for implementing new services in the area of asset management. Not only do business models have to be created, the implementation of an IT solution becomes necessary for using a data management platform for services. Mohseni et al. [30] stated that a management tool that integrates different aspects is necessary to manage an asset successfully. Müller et al. [32] explained how to realize access to field device information by means of an information server. A reference architecture for condition monitoring was presented by Wollschlaeger et al. [33]. Zampou et al. [34] deduced an architectural framework for environmental performance monitoring of machines.

Results indicated that many publications emphasize the importance of generating services out of installed base management (see Table 3). The existence of different data sources are also part of many publications, in contrast to the topic of creating a digital twin. Information architectures for asset management were also a research topic. But researchers are mainly focusing on condition monitoring data to offer services. Using existing data to describe components, machines and whole plants and enriching them with real-time data is not the focus of research. Therefore, to the best of our knowledge, there is no information architecture existing which is meeting the requirements resulting from the project goal. An information architecture for installed base management to enable smart services is still missing.

3.3 Requirements on an Information Architecture

A series of focus group discussions with different employees from an international engineering and manufacturing company was conducted to ensure creating an information architecture for installed base management that is relevant in practice. The participants came from the fields of business process consulting, application development, product management, service account management, and technical customer service. For a better structure, the discussion was divided into three parts: objective of the information architecture, general structure, and information architecture design.

The focus group stated that the objective is to be able to structure and standardize installed base data. Organizing the data into structures is important to simplify its further use [33]. Aggregating data from different sources should be enabled to create a basis for installed base management because using existing data prevents duplication of data. This means that existing data should be used and imported as required. Existing data, manually captured data and sensor data should be brought together in order to create a digital twin. To simplify subsequent analyses a uniform structure of components and machines should be ensured. The focus group recommended referring to the superior object of a component by creating a hierarchical structure. A structure from general to specific is named as suitable to represent a machine and its components.

Data quality is an important factor in installed base management [22]. The quality of data has to be ensured for successful asset management and therefore for installed base management [8]. It is mentioned by the focus group that the applicability of the information architecture should not be limited to the German-speaking area. General formats should be found because engineering and manufacturing companies often operate worldwide. The possibility of using a single information architecture for installed base management to enable smart services contributes to avoid isolated solutions. Regarding analyses of the data participants of the focus group mentioned that it should be possible to analyze structured as well as unstructured data like free texts. It is stated that sometimes it is not possible to find a uniform format, e. g. to describe the current condition of a machine. Analyses across machines and plants should also be possible. Diverse access rights for different persons would contribute to transparency.

3.4 Information Architecture Design

With focus on the requirements determined a conceptual model of the information architecture was designed (Figure 2). The first layer describes the data storage and processing. Many different types of data have to be considered to be able to reach the objective of a digital twin. For example, data generated during the production phase of a component is important. Another data pool that was discussed by the focus group was the topic of successor data. The requirement is guaranteeing that only current products can be sold. The orientation on the product lifecycle helps to meet this requirement. Another source of data considered is the installed base itself. This data is mainly collected on-site by service technicians and includes the installed base structure, a condition description of the whole machine and a description of the individual components. As required by the focus group condition monitoring data such as sensor data were also considered. The data is stored in different systems, depicted due to a systems sub-layer. All data saved in different systems is transferred to a database management system to relate the data for a component or machine. The second layer concerns services. They are necessary to generate value based on the digital twins created. On the one hand the data of components, machines and plants have to be analyzed. It is also possible to compare the data across components, machines, or even plants. On the other hand a knowledge management is necessary to turn data into information. E. g. when sensor data indicated an anomaly, knowledge is necessary to interpret the data and to give advices to the machine operator. Tools such as mathematical models may also help evaluate the analysis results. The third layer concerns the presentation and is the interface for the participants of the value network. Role-based user interfaces enable to individually define read and write permissions.

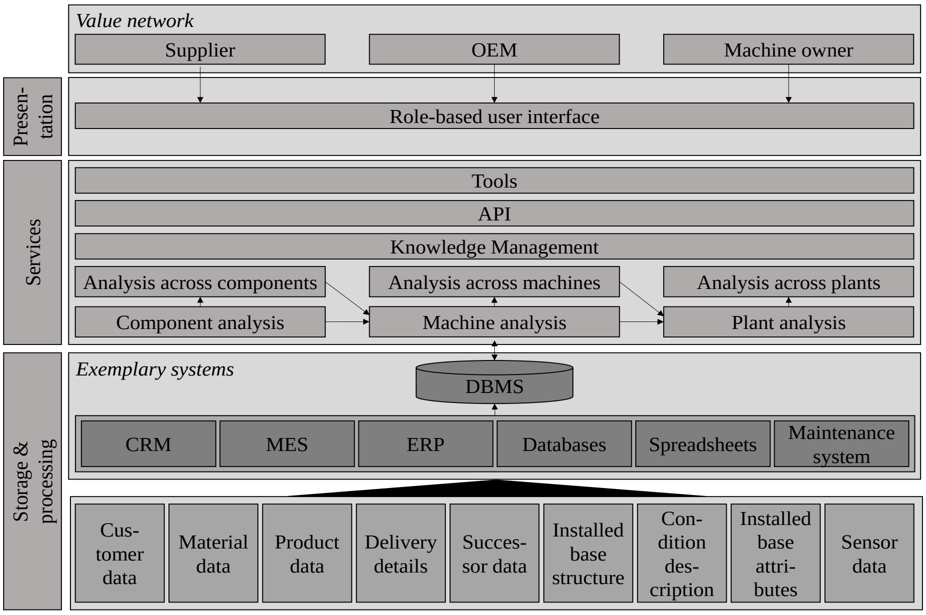

Figure 2. Conceptual model of the information architecture

3.5 Evaluation and Optimization

The implemented information architecture was evaluated in a test run. Real installed base data collected in a production site was organized through the architecture to identify optimization possibilities. Proving a conceptual model in practice leads to great improvements [36]. With the test run, it was ensured that the platform is applicable in practice as an applicability check is an essential part of a research process [41]. Additionally, focus group sessions as part of the evaluation helped to further improve the information architecture [16]. Therefore, a series of focus group discussions with participants from the application development, product management, service account management, and technical customer service of an engineering and manufacturing company were conducted to find further points for improvement.

With basis on the information architecture it is possible to create a digital twin of the machine. The focus group appreciated the fact that existing data from other databases can be added to the respective component. For example, information on production already stored in a system can be assigned to the respective component. But it has to be ensured that the information imported is also understandable for external groups. The use case that was worked out as an example for smart services included the visualization of analyses results and further information about the machine, its current state and its environment. It is also possible to partially import data and to complement it with manually entered data. All predefined installed base data could be implemented and standardized. Documents and photos could also be attached to components. It is mentioned that it should be easy to integrate new databases or spreadsheets. When using the serial number to insert existing data, it should be ensured that this data is reliable and kept up to date. Furthermore, it should be ensured that the data storage and structure is consistent for the different components and machines. This is necessary to automatically analyze the data for offering smart services subsequently.

In accordance with the fifth cycle of ADR, the points of criticism were taken up to optimize the information architecture and to create the final artifact. The valuable recommendations led to improvements of the information architecture. Thus, the evaluation helped to further simplify the creation of a digital twin of machines and whole plants with the objective to offer smart services for machine owners.

4 Formalization of Learning and Discussion of Results

Following the ADR approach, an information architecture to manage installed base data was developed. The five cycles presented in this research method were used to create an artifact that is relevant in practice. Several focus group discussions and a test run were conducted to ensure practical relevance. Through formalization, the learning was converted into general design principles to contribute academic knowledge to the research field (Table 4). At the beginning of the project, transparency was named as a challenge to create a digital twin of a machine. This means that it has to be clear how the structure of the digital twin is designed. It ensures that the structure is understood by different persons and also facilitates analyses. As it should be possible to identify the components, they have to be named uniformly. Nevertheless, an unequivocal number for each component should exist to enable locating a specific component. In the presented project, each component had a serial number for clear identification. For example, this is important when a component has to be replaced because it is affected by a production error. Standardized data is a precondition for further analyses and evaluation. For the same information it should always be used the same data format. The structure as well as information does not only have to be understood by employees of only one apartment or a single plant but in the whole company what requires international valid regulations to avoid misunderstanding. The participants of the focus group discussions that were asked regarding their requirements towards an information architecture worked at a component supplier. But as there are several participants in the value network apart from component suppliers, different perspectives on the digital twin are necessary. For example, machine owners are primarily interested in analyses concerning their own machines and plants. A role-based authentication is the tool to realize this. All named design principles contribute to an easy analysis and evaluation of the collected data across components, machines and plants. It is depicted in the services layer in the developed information architecture. As it is not possible to structure all data, for example because of free texts from employees in the field, semantic analyses should also be enabled. A service orientation of the information architecture ensures that tools such as mathematical models can be integrated. Real-time data handling is inevitable to be able to store and process sensor data.

Table 4. Set of design principles

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	

The information architecture enables to offer smart services through analyzing and evaluating installed base data. From a supplier's or an OEM's perspective it becomes possible to see the machine owner's needs in the short and medium term. Building on this, further services can be offered. The chance of participating in future projects is higher because of the direct contact with the machine owner. As a consequence, sales and customer satisfaction as well as loyalty are increasing. The consequence is a necessary service orientation because it is only possible to generate value out of the analysis results when offering services. For example, in the described use case visualizing data and information was important. In the information architecture this is represented due to the presentation layer. Tools may be necessary to realize individualized smart services that are carried out automatically. As results from condition monitoring data such as sensor data are an important part of the digital twin, real-time data handling is necessary. In the information architecture the data storage and processing layer represents this.

5 Limitations and Further Research

The created information architecture provides the opportunity to manage installed base data efficiently. However, certain limitations have to be considered. The information architecture was designed in a project of an engineering and manufacturing company. Installed base data collected by service technicians and existing data of the company were used as basis for defining the necessary data types. This was supplemented by requirements stated during a series of focus group discussions in the same company. When talking about an installed base management different participants of the value network have to be taken into account. In the presented project it is focused on a component supplier and its requirements. Therefore, it cannot be excluded that the architecture has to be adapted for other participants. In future research the requirements of other participants of the value network will be focused. Real-time data was no part of the test run. The company did not provide real-time condition monitoring data, thus it was not possible to perform a test run for this kind of data. Therefore, it cannot be said whether adjustments are necessary to be able to handle this high amount of data.

As the architecture was developed and tested in the headquarters in Germany, it is not sure whether the transfer to other languages is possible without much effort. The data were mainly stored and structured in German and a transfer to other languages was not necessary in the test run. The information architecture provides the opportunity to unite different data types and to standardize them. Smart services based on installed base management can be provided. Depending on the offered service, it could be necessary to expand the architecture. Using the information architecture for other smart services apart from the proposed use case will be tested in the future. Evaluating the information architecture flexibility and extensibility is another interesting approach for future research. Similar restrictions regarding the adaptability apply to the installed base data. It is not certain whether it is possible to standardize all data types in the future because future requirements are not yet known. Restrictions also apply to the evaluation of the information architecture. The information architecture was evaluated in a test run and not over a longer period in practice. Therefore, the information architecture was not checked under real conditions. The evaluation with other data may also lead to further enhancements and optimizations. Furthermore, it would be interesting to evaluate the information architecture and the developed design principles in focus group discussions with employees from different participants of the value network.

6 Conclusions

In this article, an information architecture to offer smart services based on installed base management in the engineering and manufacturing industry was worked out. Following the ADR approach, requirements on an information architecture for an engineering and manufacturing company were developed in a series of focus group discussions and due to a literature review. Structuring and standardizing installed base data to be able to analyze and evaluate them afterwards is inevitable to provide smart services. As an example a use case for a smart service was worked out. Based on this, the information architecture was created and refined. This was also done through several focus group discussions. Considering the discussion and limitations, the information architecture contributes to theoretical and practical knowledge. From an organization’s perspective, the information architecture enables to create a digital twin to offer individualized smart services. Answering the research question, formalization of learning led to design principles which contribute to academic knowledge in this area. Both the developed information architecture and design principles for creating an information architecture provide the basis for future research and expanding and optimizing the digital twin of machine owner’s installed base.

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