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Proactive maintenance as success factor for use-oriented Product-Service Systems

Konrad Exner[a,b]*, Christian Schnürmacher[a], Sebastian Adolphy[b], Rainer Stark[a,b]

[a]Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany
[b]Fraunhofer Institute for Production Systems and Design Technology, Pascalstraße 8-9, 10587 Berlin, Germany

* Corresponding author. Tel.: +49-30-39006247; fax: +49-30-39006246. *E-mail address:* konrad.exner@tu-berlin.de

Abstract

In use-oriented Product-Service Systems (PSS) the ownership of the product remains with the provider who is responsible for maintenance, repair and overhaul [1]. Thus the risk of machine unavailability is transferred from the customer towards the PSS provider. In order to minimize this risk the provider needs to reduce unscheduled downtimes to enhance machine availability. Hence proactive maintenance is an important success factor for providing this PSS type [2]. In practice, manufacturing equipment providers struggle to derive the required information for providing proactive maintenance from the existing data and thus potentials remain unused. One of the problems for many companies in this context is the missing knowhow for managing and analyzing this high amount of data. This issue is discussed in research and practice under the topic “Big Data” [3]. This paper focusses on discussing different approaches for data gathering, analysis and interpretation as well as associated challenges. Drivers and hindering factors are introduced and solution approaches are provided. These aspects are analyzed in a case study in collaboration with a material handling manufacturer which was conducted in one of the transfer projects of the Collaborative Research Center Transregio 29 which addressed the dynamic interdependencies of products and services in the production area.

Keywords: Product-Service Systems; Proactive maintenance; Data analysis

1. Introduction

Providing Product-Service Systems to their customers is a valuable opportunity for manufacturing companies in order to differentiate themselves from their competitors and thus increase their competitiveness [4]. For this reason PSS have gained tremendous attention in research and industry over the past years [1, 5]. Unfortunately, companies struggle to transform from an Original Equipment Manufacturer (OEM) towards an Original Solution Provider (OSP) [2, 6]. A famous example comes from the Michelin Group which launched the Michelin Fleet Solutions (MFS) program in 2000. This tire-management solution offer has been designed for large European transportation companies like Schenker and TNT. Instead of selling tires, Michelin started to transform towards an OSP by selling kilometers. Three years after the start of the program Michelin was facing critical challenges. Due to issues within the sales team, wrong cost calculations and resulting losses as well as missing acceptance of the solution by the customer the program was about to fail. With the help of a consulting firm Michelin had to undertake considerable efforts to make this program profitable [7]. Today, the program has about 500.000 contracted vehicles and approximately 1.800.000 tires managed with 1 hour and 49 minutes of average repair time for assistance services [8]. As we can see in this practical use case, the challenges associated with the transition from an OEM towards an OSP are manifold. These challenges range from the implementation of a service strategy and a product as well as service-oriented corporate culture over establishing a working service infrastructure to the qualification of service and sales employees [2].

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2. Problem statement and research approach

One part of the challenges associated with the transition from an OEM towards an OSP is associated with the collection and analysis of the usage data and condition data [6, 9, 10]. This applies especially in case of providing a use-oriented PSS, because the risk of machine unavailability is transferred from the customer towards the PSS provider and proactive maintenance becomes an important success factor. In order to analyze the potential this paper focuses on the following research questions:

- Which are the specific challenges for manufacturing companies when providing a use-oriented PSS in combination with proactive maintenance?
- Which are the existing approaches for providing proactive maintenance and how should a reference process be defined?
- Which are the most important issues for future research to enable manufacturing companies to provide use-oriented PSS in combination with proactive maintenance?

In a first step the authors describe the research approach for answering these questions (cf. chapter 2.1). Afterwards the authors give a short overview of the state of the art in the research field in chapter 3. In the following chapter 4 an accompanying use case is illustrated before the findings of the use case are described in chapter 5. Afterwards, PSS specific challenges and the overall research results are presented in chapter 6. Finally, the authors give a short conclusion and an overview for future research fields regarding the addressed topic in chapter 7.

2.1. Research approach

The research approach divides into a literature review to identify the state of the art in the field of proactive maintenance, a case study and accompanying discussions with experts in the research field. The case study has been conducted with a material handling manufacturer who has transformed from a product centered company towards a provider of products and services. The case company is now planning to provide proactive maintenance with the long-term goal of providing a use-oriented PSS. In combining the findings from the literature review with the practical experiences of the case study a process cycle for the planning, implementation and continuous improvement of proactive maintenance is introduced in chapter 5. Additionally, PSS specific challenges and a capability stair step are presented in chapter 6.

3. State of the art

The search term "proactive maintenance" in the data-base "Scopus" revealed 426 results with the first publications starting in 1986. This shows that this topic is not new and has gained tremendous attention in research and industry over the past years. The basis of the literature research was formed by these findings combined with the results of searching the database for the terms "condition based maintenance" und „condition monitoring". Cross references were also used to identify relevant publications. All findings have been analyzed by manually reviewing title and abstract.

In general two maintenance strategies are described in literature - reactive and proactive maintenance. Reactive maintenance is unplanned and takes place after error emergence. Proactive maintenance is planned and is performed before an error occurs. Furthermore, proactive maintenance differs in preventive and predictive maintenance. Performing preventive maintenance means to maintain the machines dependent on fixed time intervals (e. g. every year) or dependent on the use of the machine (e. g. every 10.000 operating hours). In contrast predictive maintenance is based on the actual condition of the machine. The condition of the machine is monitored continuously and if limit values are exceeded the maintenance could be conducted before an error occurs. This so called condition based monitoring is becoming more and more relevant in industrial practice. [11] The described taxonomy of maintenance philosophies is illustrated in Figure 1:

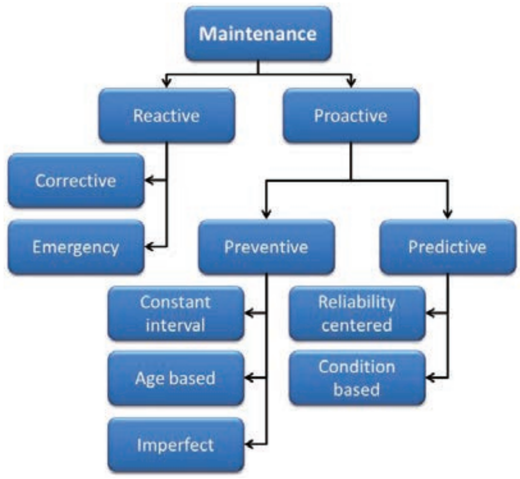

Figure 1. Taxonomy of maintenance philosophies. [12]

Jardine et al. describe the condition based monitoring process in three basic steps (cf. Figure 2). The first step is the "data acquisition". In this step, event-data (e. g. data from installation or maintenance) and condition monitoring data is captured. In this context condition monitoring describes the continuous process of data acquisition which allows reliable conclusions on the machine condition (e. g. vibration, oil analysis, moisture, acoustic and weather or environment). The next step is "data processing". In this stage the gathered data needs to be revised and analyzed by the respective mathematical analysis model including life prediction and uncertainty propagation [13, 14]. The last step is "maintenance decision making". In this stage the maintenance activities are performed to prevent machine failure. [15]

Figure 2. Condition based monitoring process. [11]

Through today's communication technology, some aspects of condition monitoring can be performed as a remote service. This means that the services can take place wireless and over long distances. Due to industrial espionage, data security plays an important role in this context. [11] Even though proactive maintenance and in particular condition based monitoring have been on the research agenda for several years, further research potential can be identified. One important challenge is the advancement of the sensor technology to make condition monitoring more applicable for the industry [16]. Another existing problem is that the required data belongs to the customer and not to the manufacturer. This results in a number of legal questions concerning the usage of this data. Therefore, new legal regulations are required. Eventually, new business models need to be developed to enhance the sales opportunities [11]. In this context, PSS is a promising approach.

4. Case Study

The case company is a supplier of material handling equipment as well as services with production on five continents. The sales and service network operates in more than 60 countries. To stay competitive and strengthen the market position the case company is planning to provide proactive maintenance with the long-term goal of providing a use-oriented PSS. The intended maintenance concept is illustrated in Figure 3:

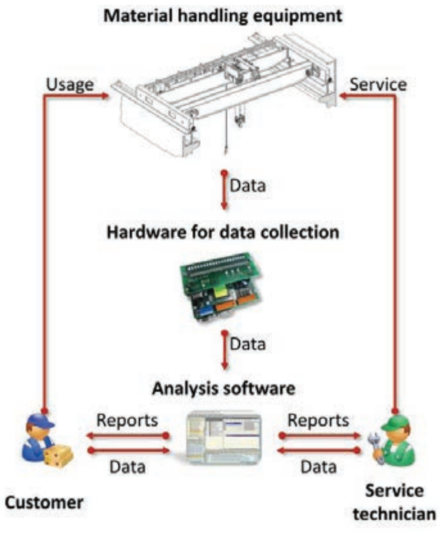

Figure 3. Intended maintenance concept of the case company.

The company started to gather use data of their material handling equipment (e. g. operating hours) a few years ago. Currently they are facing the challenge to derive the needed information out of this data in order to perform proactive maintenance. The main challenge is the identification of indicators for the errors which lead to unwanted downtimes of the material handling equipment. For instance, after how many operating hours the material handling equipment needs to be maintained to prevent the occurrence of a specific error. To find these indicators different statistical methods like the correlation analysis have been used, but the complexity of the data and the many possible correlations make it extremely difficult to draw clear conclusions.

The main objective of the case study has been the identification of challenges associated with the provision of proactive maintenance in combination with a use-oriented PSS and to define a reference process for providing proactive maintenance in combination with a use-oriented PSS (cf. chapter 2). Therefore, the used approach of the case company for providing proactive maintenance was analyzed based on workshops and interviews. The lessons learned were used to create the proactive maintenance process cycle presented in chapter 5 as well as to derive the PSS specific challenges and results in chapter 6.

5. Findings

The findings which are presented in the following conclude the state of the art described in chapter 3 and the case study presented in chapter 4. They comprise a generic proactive maintenance process cycle and the comprising activities. The process cycle has been developed based on the results of the interviews and workshops including iteration and evaluations with the case company. The activities for providing proactive maintenance are defined in a process cycle (cf. Figure 4) which follows the principle of continuous improvement and contains the phases "planning", "execution", "monitoring" and "analysis and decision".

Fig. 4. Proactive maintenance process cycle.

This process is based on the Deming plan-do-check-act (PDCA) cycle which is a methodology for quality improvement [17].

5.1. Planning

The goal of the planning phase is to accomplish all requirements for executing the proactive maintenance activities. The phase divides in the activities “define critical errors”, “identify causes and indicators”, “define limits and actions”, “define price model” and “perform feasibility analysis”. These activities will be described in detail in the following section.

Many companies already record condition data of their machines without knowing if this data really provides them with the needed information for performing proactive maintenance. In the use case the material handling manufacturer captured a variety of use data without knowing if this data provides him with the needed information to predict all critical errors. In the worst case the captured data does not provide enough information to reduce the risk of unwanted downtimes to the defined limit. In that case additional data needs to be gathered which would lead to extra costs. As this approach is not target-aimed, the first step of the defined proactive maintenance process cycle is the definition of critical errors. These include all errors or combinations of errors which result in machine damage or failure. It is important to limit the analysis to the critical errors first in order to achieve a reasonable cost-benefit ratio. Other errors can be considered in a later iteration of the process cycle to make the failure prediction more accurate. As most manufacturing companies provide product related services like maintenance repair and overhaul it is comparatively easy for them to define which of the errors are critical. Referring to the use case, this knowledge is located in different fields of the manufacturing company. Therefore, employees from all involved departments need to be integrated in the definition of these errors, especially experts from field service and customer support. Companies without product related services in their portfolio have to invest more effort to complete this activity. To reduce this effort collaborations with their customers and external service providers are advisable.

After the definition of all critical errors the related causes and indicators need to be identified. Since not all causes are obvious and some errors might have more than one cause this task is a big challenge. The needed effort is highly dependent on the complexity of the machine and the existing information on the errors and its causes. To identify the causes existing methods like the 5-Why-Method, Cause and Effect Diagram and the Fault Tree Analysis can be used.

Following the identification of the causes the next task focuses on the respective indicators. It is important to identify all indicators which enable the limitation of the risks of machine failure to a minimum. Additionally, a range of indicators provides the company with the option to monitor only a selection and thus reducing the emerging costs. The increasing risk needs to be considered before taking this decision. More information on this topic is given in the description of the activity “perform feasibility analysis”.

Identifying all indicators is a big challenge for all companies and cost a lot of resources. Additionally, a lot of knowledge about statistics and other mathematical fundamentals is necessary to identify all correlations. Companies often do not have this expertize, thus new job profiles (e. g. “Data Analyst”) become more important.

Completing identifying the causes, the limits for the indicators need to be defined depending on the accepted risk of machine damage or failure. As this influences the service intervals and thus has an impact on the costs, this is an important strategic decision. If the limits are too high the provider would perform a service which might not yet be necessary and therefore cause higher costs. Otherwise, a low limit would increase the machine damage and failure probability.

The next step comprises the service activities. For all defined errors and its respective limits the service activities need to be determined. To guarantee an immediate and smooth service it is important to define clear and lean processes. Otherwise, the additional costs of the data gathering and analysis will not be compensated.

After describing planning activities the price model has to be defined and a feasibility analysis needs to be performed. Firstly, the willingness of the customer to share the required data with the provider needs to be assessed. Legally the data belongs to the operator of the machine and only if he agrees to transfer this data to the provider he is allowed to use it. Secondly, it needs to be assessed if the required data can be captured with the required accuracy and reliability as well as reasonable effort and acceptable costs. An important influencing factor is the available technology which constantly develops and thus needs to be analyzed in detail before making a decision. At the end of this activity stands the decision whether the provision of proactive maintenance is feasible or not. Depending on this decision the process cycle continues with the next phase or is cancelled.

5.2. Execution

The target of the execution phase is to implement all planned activities in order to enable proactive maintenance. At the end of this phase all defined indicators are continuously monitored and proactive services are performed as required. The execution phase divides into the activities “develop monitoring equipment”, “develop analysis software” and “install monitoring equipment”. In the first two steps of this phase the monitoring equipment and the analysis software are developed. Depending on the internal knowhow the equipment and the software can also be developed by external partners. Important factors for the monitoring equipment are wireless data transfer, transfer of the operating data in real time and data security [2]. Subsequently, the developed monitoring equipment and the analysis software need to be installed to start gathering and analyzing the data. Afterwards, the required prerequisites for performing proactive maintenance are fulfilled and the service provision is executed depending on the information derived from the gathered data.

5.3. Monitoring

In this phase the running proactive maintenance processes are monitored. The service costs and revenues are tracked to check the profitability of the new business model. Additionally, the machine failure rate is monitored to verify the effectiveness of the adopted measures.

5.4. Analysis and decision

In this phase the monitored data is analyzed and a decision concerning the continuation of the proactive maintenance is made. If the costs for the service exceed the revenues the price model of the proactive maintenance must be reviewed and adopted. Furthermore, the machine failure and damage rate needs to be analyzed. If the targeted rate is surpassed new errors and the respective indicators or new indicators to the existing errors need to be adapted regarding the machine monitoring. In these cases a new proactive maintenance process cycle is started. If the analysis shows no deviation from the target state the proactive maintenance as well as the monitoring of the processes will be continued without any changes.

6. PSS specific challenges and results

In this chapter the PSS specific challenges in the field of proactive maintenance (cf. chapter 6.1) as well as a capability stair step (cf. chapter 6.2) are described.

6.1. Challenges

The sales departments of manufacturing companies are facing problems to convey the benefits of proactive maintenance to the customer. Especially, the customer is often not willing to pay for an extra service during the warranty period. Therefore, it is difficult for manufacturing companies to generate revenues for proactive maintenance during this phase. [9] Business models based on principles of use-oriented PSS have the potential of overcoming this challenge. The material handling manufacturer of the use case pursues the long-term objective of providing a use-oriented PSS. In use-oriented PSS the ownership of the product remains with the provider who is responsible for maintenance, repair and over-haul [1]. In this case the risk of machine failure is transferred to the provider which is a substantial advantage for the customer. Despite this advantage, use-oriented PSS comprises specific challenges connected to the topic of proactive maintenance. These challenges were identified based on five lead question based, 90 minutes interviews with participants of the case company (two project manager, one service design engineer, one product design engineer, one service technician) and are described in the following.

Reimbursement: As mentioned before in use-oriented PSS the risk of machine failure is transferred to the PSS provider. In order to compensate this risk increase the provider uses proactive maintenance to prevent machine failure and thus avoids reimbursements. Besides, predictable factors like false usage of the equipment could also cause machine damage or failure. This influencing factor is nothing the provider is responsible for. Therefore, he has to ensure that in case of machine damage or failure caused by false usage he is able to prove that he is not responsible for the machine downtime to disclaim him from warranty. Even though the condition data of the machine could indicate false usage additional information is needed by the provider to secure him from this issue. Hence the monitoring of use data becomes a critical aspect when providing a use-oriented PSS with proactive maintenance. This gives the provider the opportunity to prove his innocence. Additionally, operating data can provide insights on future machine damage or failure. As a consequence the machined failure rate can be reduced further by identifying use data indicators for specific errors and defining limits for these indicators. To consider this aspect in the pro-active maintenance cycle, additional activities need to be implemented in the planning phase.

High importance of practical knowledge and experiences: The risk transformation forces the provider to reduce the machine failure rate to a minimum. Without practical knowledge and experiences in the field of proactive maintenance this low machine failure rate will be hard to achieve from the beginning. Therefore, the provider needs to gather this experience before the provision of a use-oriented PSS. For this reason he has to convince the customer to gather the condition and use data in advance and without any benefit for the customer. As the customer has no immediate value the provider has to develop marketing concepts to convince the customer of the long term benefits. Furthermore, he should not demand any kind of payment from the customer at that point. The gathering and analysis of the data shout be seen as a long term investment for the provider too as this is one necessary requirement for providing a use-oriented PSS and thus for increasing their competitiveness in the future.

Machine availability calculation: The provider of a use-oriented PSS guarantees the customer contractual agreed machine availability. The use case clarified, that it is extremely difficult to calculate and prove this availability. To do so additional use data is needed which has to be considered in the planning phase of the proactive maintenance process cycle (cf. chapter 6.1).

6.2. Capability stair step

Based on the literature review and the case study the capability stair step (cf. Figure 5) has been iteratively developed and evaluated within the workshops with the case company. The initial motivation has been a management request for a high-level framework regarding the transformation process from the case company. This model represents the necessary steps to become a service-oriented as a generic guideline, thus supporting companies with the transformation process. The main stages are “optimization of the status quo”, “transformation to a data-driven company” and eventually “transformation to a service-oriented company”.

7. Conclusion and outlook

This paper gives an overview on existing proactive mainte-

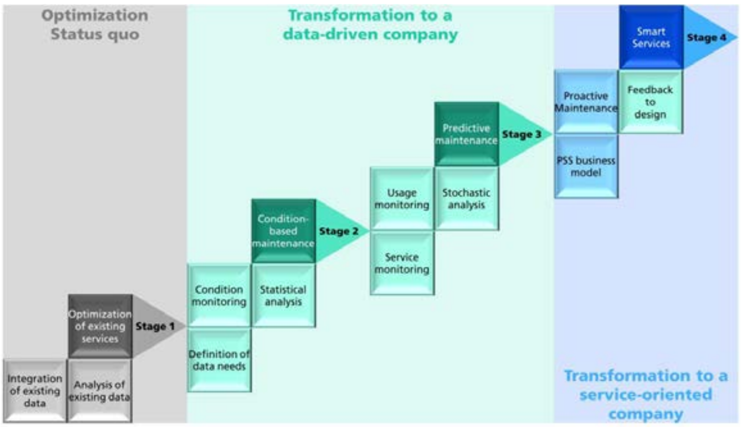

Figure 5. Capability stair step towards a service-oriented company.

nance approaches and how proactive maintenance is connected to the provision of a use-oriented PSS. A proactive maintenance process cycle was developed using the input from literature and the case study described in chapter 4. Additionally PSS specific challenges on this topic were introduced in chapter 6. A limitation of this study is the restriction to one case company. Therefore, the results have to be evaluated with further companies. In summary, it can be stated that proactive maintenance in combination with a use-oriented PSS business model is a great opportunity for manufacturing companies to differentiate themselves from their competitors and thus increase their competitiveness. However, there are some challenges that need to be overcome. Besides the risk of false use of the equipment by the customer the persuasion of the customer is a huge challenge as the benefits for him are not trivial. Future research should focus on marketing concepts to effectively communicate the customer benefits. Additionally the data gathering for monitoring the indicators needs more precision and must become more cost-effective. Eventually, the concepts of smart service illustrated in the capability stair steps needs to be analyzed and discussed in a further study.

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