First Steps to the Digital Shadow of Maintenance Services' Value Contribution

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Abstract. Industrie 4.0 is said to have major positive effects on productivity in manufacturing companies. However, these effects are not visible yet. One reason for this is the lack of understanding of maintenance services as a crucial value contributing partner in production processes, although scientific literature already highlighted the importance of indirect maintenance costs. In order to retrieve the unused potential of maintenance services, a digital shadow in form of a sufficiently precise digital representation is required, providing a data model for the value of maintenance actions so that asset and maintenance strategies can be optimized later on. Using case study research for process manufacturers, the first research contribution of this paper consists of 21 value contributing elements being identified. The second contribution is a reference processes model, showing seven major process steps as well as the required intra-organization interaction on an information technology system level. Therefore, it provides the base for the missing data model shaping the targeted digital shadow of maintenance services' value contribution.

Keywords: Industrie 4.0, digital shadow, maintenance services, maintenance value contribution, intelligent maintenance systems.

1 Introduction

The advance of the digital interconnectedness in industrial companies during the past years, also referred to as *smart factories* or *Industrie 4.0*, has increased the awareness of manufacturing companies for their own digital transformation in order to keep up with the global competition. However, that interconnection between cyber-physical systems and people, combined with an unlimited access to real-time data [1, 2] that could drastically accelerate critical entrepreneurial decision making [3], has not led to an increase in productivity across those companies so far [4], as often Industrie 4.0 use cases do not become successful business cases especially in maintenance departments. One reason for that are still dominating isolated information technology (IT) systems within the companies, which prevent information getting from the information source to a decision-making stage, so that also intelligent maintenance applications or assistance systems [1] cannot fulfill the promised potential [5]. Another reason is the lack of understanding of maintenance services as a crucial value contributing partner in manufacturing companies' production processes. V*alue* thereby represents the positive change of a manufacturing company's balance sheet in general or even the increase in profit (EBIT) or return rates (e.g. ROCE). This results in investments for maintaining the assets, e.g. maintenance personnel and equipment, being held back. Additionally, a regular adjustment of the cost-optimal mix of maintenance strategies consisting of reactive, preventive and even predictive measures according to the asset condition and risk assessment are not executed effectively [6]. Both factors may not result in an increase of *direct maintenance costs* from spare parts, labor and external service providers in the short term, but they lead to a significant increase of *indirect maintenance costs*. These are the result of, for instance, lost contribution margins due to unplanned downtimes [7], subsequent contractual penalties or even loss of customer orders [8]. Thus, entrepreneurial decisions, e.g. choosing the right maintenance strategy mix and making sustainable asset investments, are made on an incomplete information basis [9].

The main reason for that lack of information or visibility is not technological but organizationally driven [10]. Currently, there is no approach available to identify that information for costs or effects in manufacturing companies on an information system level, which is required to determine the value maintenance services can add to the company's balance sheet. So, in terms of the concept of Industrie 4.0, a *digital shadow* is required in order to retrieve the full potential of a company´s digital transformation [11].

2 Theoretical Background

2.1 The Digital Shadow as Part of the Internet of Production

The digital shadow represents "an integrated database that generates a sufficiently precise digital representation of the whole enterprise in real-time", primarily on a process level [12] and therefore must be differentiated from the *digital twin* as a simulation-capable digital representation of a physical asset [13]. In that context, the digital shadow serves as a transition layer within the 'Internet of Production' providing a domain-specific data model connecting different IT systems [14]. Thus, the digital shadow does not represent an optimizing application in the first place but forms the required basis for a variety of analytical applications (e.g. maintenance/asset investment strategy) improving the management's data based decision making [15].

The concept of the digital shadow was applied to production environments in the first place in order to increase the visibility in factory and production planning [16]. It was then adopted to industrial services and provided a reference process model as initial point for a sufficient data model which focused on the service execution level only [11]. However, a comparable approach defining value contributing elements, a reference process model as well as a data model for the value of maintenance services is still unavailable.

2.2 Requirements for a Digital Shadow for Maintenance Services

The digital shadow itself does not optimize decision making for maintenance services, but it serves as a tool to provide the required visibility. In order to develop it, three major steps are required [14]. First, it is required to identify and clarify elements representing the value contribution of maintenance services and to link them to specific information [11]. Second, the elements and referred information have to be linked to a reference process, fulfilling the purpose of reutilization [17]. Based on the reference process and its steps, a data model can be derived completing the definition of the digital shadow [12]. This paper contributes to the identification of the value contribution elements/information and the resulting reference process model while the development of the data model for the required time series observation of the value elements as well optimized decision making based on that digital shadow are explicitly *not* subject of this paper (see level three and four in Fig. 1).

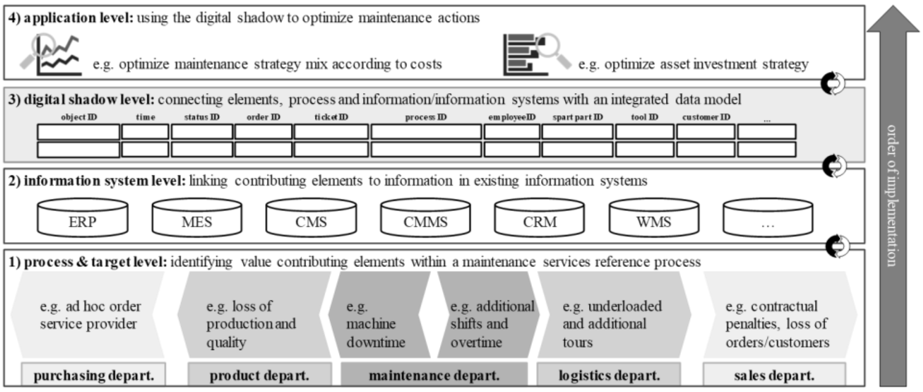

Fig. 1. Concept of the digital shadow of the value contribution of maintenance services

In scientific literature, value contributing elements of maintenance services have already been subject of discussions [18], though that previous work is generally incomplete in two specific areas. First, the value contributing elements are considered from a direct and indirect cost perspective, respectively, while positive effects of maintenance actions on the company value are not included [19]. Second, the determined elements are incomplete as they are restricted to a close maintenance perspective only and do not take into account effects appearing in other organizational units of the company (e.g. loss of customer orders monitored in the sales department). This is enhanced by the effect that value contributing elements additional to known maintenance-related downtime costs become visible with a time delay (e.g. shortened asset lifetime). Therefore this paper points out the value contributing elements particularly considering intra-organizational boundaries as well as time delays.

In order to form the targeted data model for the digital shadow of maintenance services' value contribution, a reference process model is required containing core functions (process steps), cross-section functions (e.g. reports, contracts) and a data management (e.g. resources, employees) [20]. Regarding the reference process and the related process steps, a variety of models is already described. Most of them refer to or are similar to the previous work of German standardization initiatives (e.g. DIN31051) [21]. However, those process models do not consider the existing intra-organizational exchange of data and information required to determine the value contribution of maintenance services leading to an insufficient data management. Thus, this paper introduces a reference process model focusing on the core process steps which provide interfaces to the value contributing elements and referring information across the organization and information systems. Therefore, this paper contributes the first two levels of the concept of the digital shadow as summarized in Fig. 1.

3 Methodology

In order to address the given problem of defining elements and a reference process model for the digital shadow of maintenance services, the work in this paper is based on the approach of case study research [22]. Following its eight steps, this method ensures the practical applicability of the qualitative results later on.

For this paper, we chose cases from process manufacturers. Here, the added value of maintenance services in that industry becomes clear because unplanned downtimes, for instance, have an immediate impact on the production process, thus increasing the potential of the value maintenance services can add to the balance sheet of a company. Additionally, the value contribution is expected to be high due to the loss of contribution margins due to production and quality losses [23]. Other structuring factors were the numbers of employees indicating the size of the companies as well as the complexity of assets used within the manufacturing process.

Table 1. Overview of selected cases

No.	Industry	Employees	Asset complexity
1	Steel	> 10,000	high
2	Textile	ca. 500	medium
3	Pharmaceutical	> 10,000	high
4	Automotive supplier	ca. 2,000	medium
5	Food	ca. 1,800	low
6	Food	ca. 1,200	low
7	Paper	ca. 300	medium

The cases and qualitative results were recorded in form of triangulation [22]. The identification and assessment of the value-adding elements, referred information and the reference process model were jointly modeled by experts from the selected companies, following a semi-structured interview. Moreover, the data was supplemented by internal company data, e.g. operating instructions, balance sheets and a comprehensive literature analysis. Seven case studies, as shown in Table 1, were analyzed, but no significant addition was made to the examined contributing elements, information and process steps after the fifth case study, because the findings were repetitive. Thus, the termination criteria (eighth step of the case study research approach) were met.

4 Modeling and Results

4.1 Identifying and Evaluating Value Contributing Elements

Following the methodology of case study research for process manufacturers, 21 elements were identified to have an impact on the value contribution of maintenance services. Those elements were then classified into two groups. The first group comprises all the elements which contribute a positive value to the company and should therefore be maximized, such as output and product quality increase. The other group contains elements causing additional costs that consequently influence the companies' value negatively (e.g. loss of contribution margins or contractual penalties due to missed delivery dates). In order to identify the most relevant elements out of the two groups, the elements were evaluated qualitatively according to their effect size regarding the value of the company and their significance, meaning the extent to which they can be influenced by maintenance measures directly or indirectly as shown by the framework downtime consequential costs [6].

Those elements with a great effect size and high significance to maintenance actions were identified as most relevant while other elements were excluded from further modeling (e.g. commissioning costs and image loss). The results of all identified and evaluated elements are shown in Fig. 2 were the subject of the subsequent design of the reference process model.

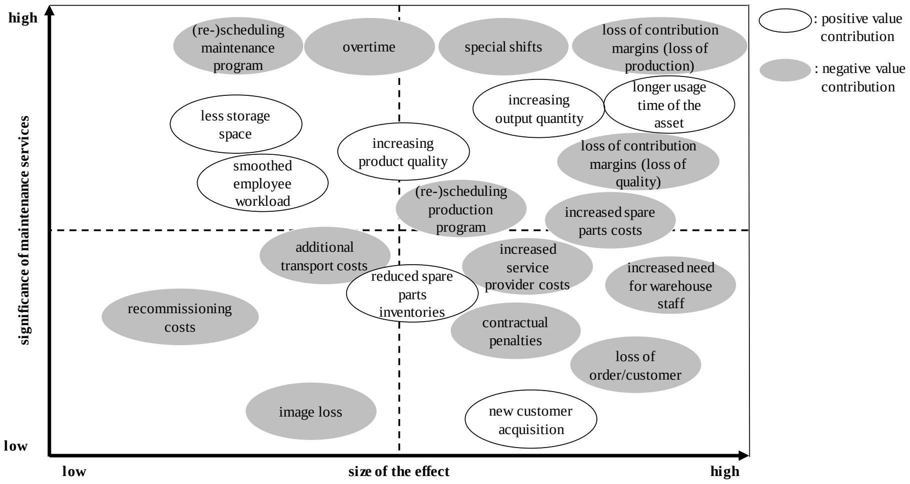

Fig. 2. Case study results for value contributing elements

4.2 Modelling of a Reference Process

In the next step, the selected elements were first broken down to their information level required to retrieve them on IT system level (s. example information in Fig. 3), also following the approach of case study research and literature review. Then, the elements and referred information were transferred into a reference process model. Fig. 3 shows the seven process steps as well as the involved departments of a company in which the relevant value contributing elements and related information are monitored (e.g. sales, purchasing and logistics). The reference process model considers them as an information source that provides the basis used to assign the elements to maintenance action as part of the shown process steps (s. examples in Fig. 3), although many value contributing elements do not occur within the maintenance departments directly but delayed. Furthermore, the process model's data management identifies all involved information technology (IT) systems, such as the computerized maintenance management system (CMMS), the enterprise resource planning (ERP), the customer relationship management (CRM), the warehouse management (WMS) or the manufacturing execution system (MES) (s. Fig. 1). Consequently, the process model allows the distinct assignment of a value contributing element and their related information (s. Fig. 2) to maintenance actions within a specified period of time. Therefore, it provides a useful basis for the central data model shaping the targeted digital shadow of maintenance services' value contribution

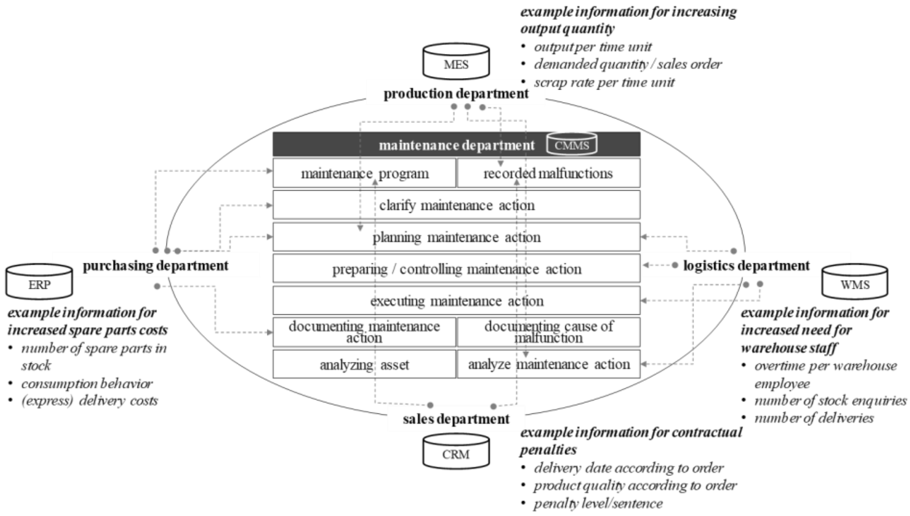

Fig. 3. Extract from the reference process for maintenance services within the relevant stakeholder environment

5 Conclusion and Outlook

This paper demonstrates that intra-organizational visibility is required to uncover time-delayed value contributing effects of maintenance actions in form of a digital shadow of maintenance services' value contribution. Using the research approach of case study research 21, elements are shown and organized by the size of their effect (impact) and the significance of maintenance services for their appearance (s. Fig. 2). Besides the dominating elements of contribution losses due to loss of production or quality, further elements (e.g. efforts for re-planning maintenance, contractual penalties) have been identified, representing an extended scientific understanding of maintenance services' value contribution. Moreover, the paper demonstrates that the information referring to the qualitative evaluated elements are monitored in different departments as well as different IT systems within a company. The presented core function of the reference process model with its seven process steps allows to connect maintenance actions with the value contributing elements and information. It sets up the basis for the data model as last key element of the digital shadow.

Hence, future research can build on the contributed model in order to describe how different IT systems on a database level can interact so that domain-specific requests can be answered with real-time data and information using entity relationship models, for instance. Furthermore, design recommendations are needed for the implementation of a digital shadow in practice. In this context, future work may also specify the identified value contributing elements on an existing KPI (key performance indicators) level so that current IT systems and management models can be adapted to the presented concept more easily. Thus, finally utilizing the digital shadow (s. Fig. 1), e.g. to choose the correct maintenance strategy mix as well as asset management strategy in respect of the whole asset life cycle, could become the key to retrieving the full potential of existing and future Industrie 4.0 solutions for maintenance services in manufacturing companies.

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