SPS12 – Managing complexity - A methodology, exemplified by the industrial sector of remanufacturing

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ABSTRACT

Compared to manufacturers of new parts, remanufacturing companies can only react passively to an increased complexity in products and processes instead of an active avoidance or reduction. For this reason a successful complexity management, created upon detailed knowledge of drivers and effects is necessary. This paper shows main aspects of a new methodological approach to manage complexity in the industrial sector of remanufacturing. The results from analyzing thousands of datasets will show focal points of complexity effects within the production process. Thus, it will be possible to identify the main drivers of complexity and develop an appropriate complexity management.

Keywords: Remanufacturing, Complexity, Management.

1. Introduction

The individual needs of the customers require many companies to be present with a diverse product portfolio in the market. With each new variant the effort in the company to manufacture a product rises. The amount of additional work is directly related to the occurring complexity of the process, which in turn is determined by the number of different versions of the products [1]. In addition to the individualization of technical products, the increasing demands for excellent production performances like short lead times, efficient use of resources and minimal emissions during product manufacturing contribute to an increase in complexity. Complexity occurs in manufacturing companies in various forms and areas of activity. According to Ulrich and Probst complexity is understood as a system quality whose degree depends on the number of system elements, the plurality of connections between these elements and the number of possible system states [2]. The complexity is equally determined by the number and diversity of elements and relationships that occur in this system, and depends also on their temporal variability [3]. To develop a methodology for quantifying complexity drivers and effects, the still very abstract formal description of complexity requires first of all the identification of theoretically possible complexity drivers and the subsequent selection of complexity drivers that are practically relevant, which especially in the addressed area of remanufacturing lead to complexity caused effects and thereby to additional costs. In this context, remanufacturing means the industrial process to repair products according to their usage cycle [4, 16]. Remanufacturing is also the value-added process step of a worldwide industry which represents about 100,000 companies with a turnover of approximately 100 billion euros [5]. Thereby, remanufacturing companies face similar challenges as well as many other industrial companies, since the number of parts is constantly rising. The wide range of original equipment manufacturers, product groups, production series, configurations and levels of quality (such as pollution, degree of wear, usage history) requires in each case specific process steps, in which the related product variants lead to many process variants. Basically the remanufacturing process of mechanical products can be divided into five main process steps (Figure 1), while the sequence of the process must be adapted to the individual original state of the used products [6].

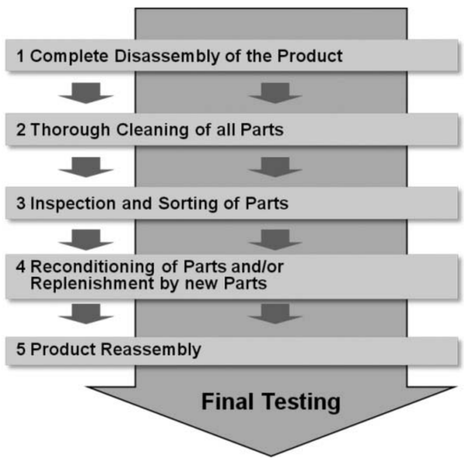

Fig.1: Main steps in the remanufacturing process. [6]

Compared to manufacturers of new parts, remanufacturing companies can only react passively to an increased variety instead of an active avoidance or reduction [1, 5]. Due to the lack of influence on the avoidance of variants, handling complexity successfully can only be reached target-oriented and through innovative, holistic approaches. [7]. For this purpose, in addition to the practically relevant complexity drivers, the effects of complexity on the production processes have to be identified in order to be converted into a model subsequently. Within the European research project reCORE - research for efficient configurations of remanufacturing enterprises – (funded by the German Federal Ministry of Economics and Technology) scientists at the University of Bayreuth are researching on the development of a methodology for handling complexity in the remanufacturing industry. In the course of this paper methodologies for quantifying the complexity of drivers and effects as well as detecting and managing them are presented in which both industry-specific and company-specific production configurations are considered.

2. State of the scientific knowledge and need for action

Progress in the context of complexity reduction can currently be identified to a greater extent in the field of logistics, especially the supply chain management and production techniques [3, 8]. Studies show, that the costs in manufacturing companies, which are caused by product and process complexity, are up to 25% of the total costs [9]. Uncontrolled complexity appears in, e.g. increased administrative expense for master and transaction data, reduced speed of production and business processes and increased error costs. As a base for effective management of complexity, a precise knowledge of the occurring negative effects and the relevant effective ranges has to be present in order to be able to categorize these effects and effective ranges. Therefore Golovatchev and Budde propose generic perspectives, such as product complexity and process complexity, and assignments of the categories of time, cost, process quality and product quality for the perspectives [10]. This approach enables the creation of an accordingly focused complexity management and exemplifies the need to categorize the identified effects and effective ranges. Approaches for handling complexity specific to the needs of the remanufacturing industry do not exist so far. Because of companies in that branch of industry that have a lack of influence on the avoidance of variation and consequently on the increased product and process complexity, a development of a new methodology for a successful complexity management, created upon a detailed knowledge of drivers and effects is necessary. This requirement is also supported by results of interviews with experts, which within the area of remanufacturing allow for the assumption that 90% of the complexity is caused by products that contribute to sales of an average remanufacturing company by only 10% [11]. So there is a need for action to develop a methodology for the quantification of complexity drivers and effects, which at first filters the practically relevant complexity drivers out of those that are theoretically described and which, based on this selection, enables the installation of a complexity management system for the remanufacturing industry.

3. Concept of the methodology

In order to manage important factors that are influencing the performance of a production process, such as control of complexity and its effects, the actual collection and measurement of complexity drivers can be seen as a necessary criterion for target-oriented complexity management, corresponding to the quote "If you can't measure it you can't manage it" [12]. As previously described, this can only be realized on the basis of detailed knowledge about the occurring complexity drivers and effects. For the illustration of the generic perspectives product and process complexity with the corresponding categories of time, cost as well as process and product quality, the approach by Golovatchev and Budde is adapted to the specific needs of remanufacturing companies.

3.1 Identification of complexity drivers and effects

For a systematic analysis of the complexity drivers and effects, a subdivision in the dimensions of size, uncertainty, diversity and dynamics [5] only suits in the field of remanufacturing is used in the presented methodology. Thereby a "dimension" corresponds to the extent of a "category" by Golovatchev's and Budde's approach. For a more detailed subdivision the target fields production planning and control, core management, organization of production as well as identification are considered as effective ranges distinguished from one another, which in turn contain the scope of a "perspective". In practice the occurring complexity drivers and effects are subsequently identified in the context of process analysis and expert interviews and assigned to the dimensions and destination fields. To make this classification, an appropriate form of presentation has to be used afterwards, in which the complexity drivers and effects are listed systematically and clearly. For such a presentation of the complexity drivers in the described case, the application of an Ishikawa or cause-effect diagram is suitable, in which causes and effects of single and multiple events are displayed in a structured manner (Fig. 2). This approach is as well appropriate to analyze complex influences on functional relationships in production processes [13].

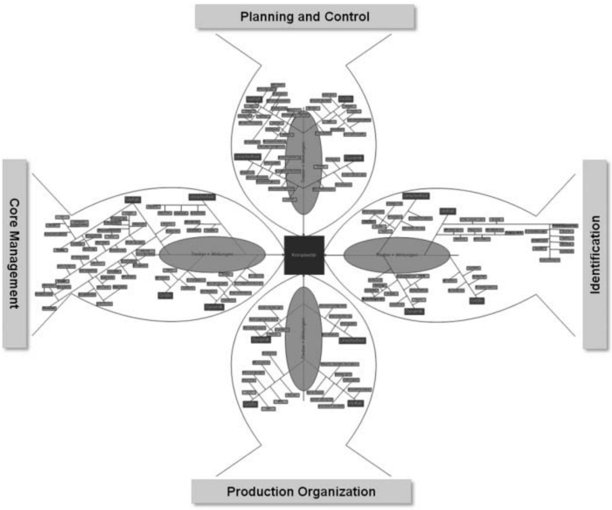

Fig. 2: Complexity Ishikawa diagram

As part of the described methodology, 57 drivers of complexity across all dimensions and target fields can be identified for the branch of remanufacturing. These drivers are displayed in the complexity Ishikawa diagram and associated with the appropriate dimensions and target fields. In this case an occurrence of the same complexity drivers in different dimensions and / or target fields can be documented, which already at this point allows an initial assessment in terms of frequency of occurrence. In the next step, the identified complexity drivers are tested as to their effects. On that point, within the boundaries of analyses in practice and additionally conducted interviews with experts, effects are again identified that are attributed to an increased complexity. Furthermore, evaluations of analyses and the carried out expert interviews provide a total of 50 different effects.

3.2 Quantification of the identified complexity drivers

After identifying the complexity drivers and effects a suitable method for quantifying them must be applied. For this purpose, the created complexity Ishikawa diagram is transferred into a calculable table in matrix form that is capable of a computer-aided evaluation. This table contains the identified complexity drivers in their respective target field and their respective dimension with the 50 different effects. Thereupon a discrete specific valuation for the combination is awarded, registering a "1" for "effect occurs," or "0" for "effect does not occur" in an integrated assessment column. This is done by taking the previously evaluated analysis results into consideration, both on a quantitative and with the help of expert interviews, on a qualitative basis. For the quantification, more than 4,800 combinations of each complexity driver, each target field, and each dimension are examined and evaluated within the evaluation table. Afterwards, the complexity caused effects are quantified and become thereby measurable for the first time within the methodology.

4. Results of the quantification of complexity drivers and effects in the field of remanufacturing

In the next step the analysis provides the number and type of effects directly caused by complexity. A subsequent analysis enables the preparation and presentation of the results by using special filters and sorting functions. This makes it possible to identify the main drivers of complexity, to quantify the resulting effects and to establish target-oriented optimization methods, derived from the results. Figure 4 shows the main result of the quantified effects, which were determined by using the presented methodology in the field of remanufacturing.

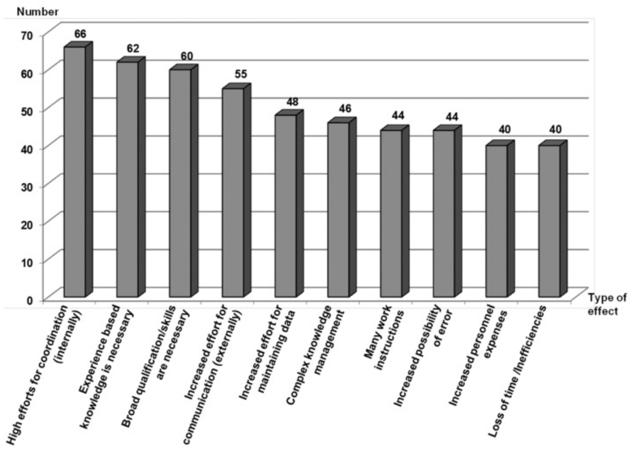

Fig. 3: The top ten effects in the field of remanufacturing

The chart shown in Figure 4 indicates that for a total consideration of the results of all dimensions and target fields, the effects "High effort for coordination (internally)" with 66-fold occurrence, "Experienced based knowledge is necessary" with 62-fold occurrence and "Broad qualifications/skills are necessary" with 60-fold occurrence represent a high proportion compared to the other effects turning up. Hence, complexity in remanufacturing companies leads primarily to a high internal effort on coordination. Furthermore, a high level of knowledge and experience of staff accompanied with a broad qualification is required in order to meet the increased complexity in remanufacturing companies. All effects have in common that they usually require individual experience-based reactions of the employees, which differ from existing standards and often require the presence of implicit knowledge. Such knowledge cannot or barely be shared verbally, but only through personal experience or by learning through the model [14]. For further analyses during the course of the methodology, the related causes -the complexity drivers- must be assigned to the identified effects. For this purpose re-evaluations are performed by using the appropriate filter functions in the evaluation table. Figure 4 shows the top ten identified complexity drivers within the boundaries of the methodology.

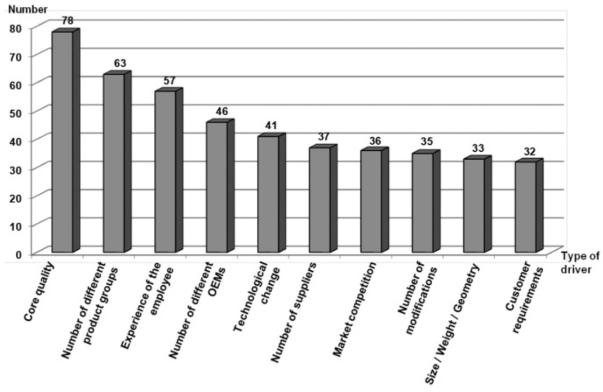

Fig. 4: The top ten complexity drivers in the field of remanufacturing

It is shown that the core quality, the number of different product groups and the experience of the employee, in addition to the other illustrated complexity drivers cause most of the effects. By accounting these complexity drivers in connection with the previously identified effects "High effort for coordination (internally)", "Experienced based knowledge is necessary" and "Broad qualifications/skills are necessary", it is immediately obvious that the so far only qualitative assumption of an active relationship can be confirmed by means of the methodology. Associating all the identified complexity drivers with the assigned effects, a ranking of all involved complexity drivers and effects based on the evaluation can be established. In addition, the target fields and dimensions can be determined, in which the complexity drivers occur with their respective effects. A division of the identified complexity drivers into the three major categories "avoid", "reduce" and "handle" [15], taken from the area of lean management, is suitable for a subsequent selection of optimization methods. This division makes it possible to preselect the identified complexity drivers for an optimization and to choose appropriate optimization measures. For giving an example, the classification of each of the three biggest identified complexity drivers into the respective general categories is described in the following. The complexity driver "quality of cores" cannot be influenced by remanufacturing companies but depends on the individual condition of use of the component. Thereby the categories “avoid” and “reduce” are out of question for a classification. Therefore the varying quality of used parts can only be optimized through an improved "handle". “High number of product groups” as the ranked second complexity driver, can be assigned to the major category "reduce", whereas here the reduction of the different methods of remanufacturing should be the aim. Employee experience as the ranked third complexity driver and success factor of an efficient remanufacturing process at the same time is assigned to the major category "avoid". A remanufacturing company should to the possible maximum extent try to preserve success-relevant employee know-how, e.g. by training or avoiding employee turnover. As discussed by Guimaraes et al. that can help to reduce the negative impact of system complexity [17]. According to this scheme, all other identified complexity drivers can be classified into one of the three major categories and then efficiency-oriented improved, by means of equivalent and geared optimization methods that are content of the major class.

5. Measuring and managing complexity effects

To make complexity effects measurable and thus visible to remanufacturers, methods for recording effects as well as indicators and their scopes have to be set. The defined methods advise remanufacturers which values in their production process have to be measured in which way. The indicators make it possible for remanufacturing companies to evaluate measured figures within fixed scopes which allow them to classify themselves. The limits of the scopes have to be defined in a first step and then in a second step have to be evaluated and adapted where needed. Besides being able to classify their remanufacturing process regarding to complexity issues the companies also need methods and tools to manage complexity effects. Therefore suitable existing optimization methods and tools are assessed to each complexity effect. The assessment evaluates whether a method or tool is suitable or even not suitable to avoid, reduce or handle the effect, depending on the previously allocated effect category (see point 4). Like in the former assessment of drivers and effects a discrete evaluation is carried out for each combination of effect – effect category – optimization method or tool. Value “1” means “method/tool is suitable”, value “0” means “method/tool is not suitable”. This way each of the 50 effects is compared to 46 methods and tools which results in an amount of 2,300 combinations documented in a two-dimensional matrix. The results are used to finally develop a web based configuration tool which allows remanufacturing companies to figure out which optimization methods or tools customized to their company related indicators are suitable for managing complexity effects in their remanufacturing process. It also enables remanufacturers to monitor their measured indicators and supports their improvement process.

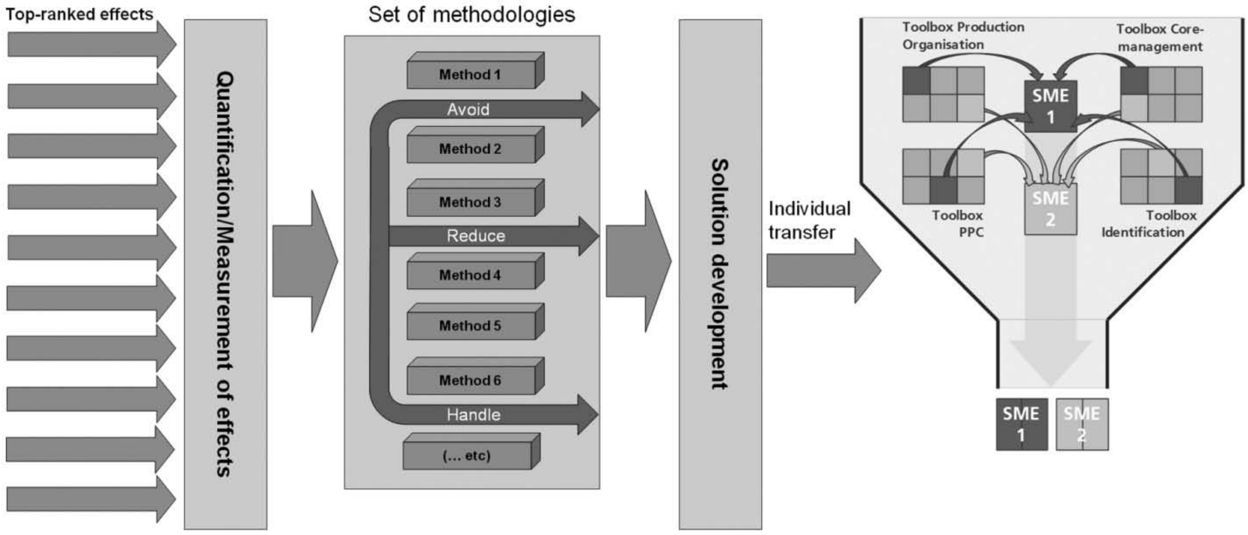

Fig. 5: Development of solutions for the reduction of effects

6. Conclusions

The described methodologies enable remanufacturing companies for the first time to detect and quantitatively evaluate complexity drivers and effects on the basis of an approach specific to their individual needs as well as managing the drivers and effects to improve their remanufacturing processes. After the formation of a hierarchy, optimization measures that are derived from the results can be initiated, which in terms of each displayed major category (avoid, reduce, handle) contribute to a minimization of the complexity induced additional effort and thus help to save additional costs that can hardly be calculated in advance. Because of their adaptability, the described methods are also suitable for other branches of industry, such as the manufacturing of new parts of complex products with a high degree of customization. This merely requires a corresponding adjustment of the occurring target fields and dimensions and a one-time identification and evaluation of the complexity drivers and effects in the way of this methodology. The described methodology for quantifying complexity drivers and effects was applied for the first time in this way and due to its design; it offers very concrete possibilities to reduce the occurring complexity in the production processes of remanufacturing company. This is a novelty especially in the field of complexity research, as in literature often very abstract approaches and methodologies are described, whose usefulness seems to be generally rather low in the perspective of a user without the necessary technical and scientific background skills. As part of further research the extension of the evaluation table in terms of identifying complexity drivers and effects will be focused in order to identify and evaluate interdependencies and causal interactions between the included complexity drivers and effects. It also has to be examined whether in future it is possible to make complexity drivers and effects monetarily assessable by means of a generated apportionment procedure based on statistical methods.

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