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Remanufacturing Process Capability Maturity Model

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Abstract

Remanufacturing is a key discipline at the end of a product's life or use cycle. Besides the economic advantages, remanufacturing is also more ecological compared to the new production of parts. Due to the rising amount of product variants and the resulting increasing process complexity, as well as the dirty old parts used, remanufacturing processes face different challenges than processes in new productions. Unfortunately, there are hardly any tools available to analyze and compare remanufacturing processes. Therefore, this paper shows the results of an analysis of remanufacturing operations by using a capability maturity model.

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Keywords: Remanufacturing; Process Assessment; Maturity Model; Operations Management

1. Introduction

The corporate landscape has changed, due to increasing competitive constraints, in the recent years [1]. Producing goods with fewer resources [2] promises significant advantages, both ecological and economical. Moreover, global trends as increasing resource scarcity, increasing commodity prices and environment protection become more important [3]. Besides classical approaches to increase the resource efficiency in manufacturing companies, there are also more innovative approaches as the Circular Economy movement, which is shaped by organizations like The Ellen MacArthur Foundation (EMF).

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The idea of this approach is, to transform our society and way of thinking from a linear approach, of producing and throwing things away, towards a circular economy, in which products can be reused, for example. The idea of the Circular Economy is well described in the Circular Economy System Diagram, developed by the EMF [4]. One key element of the Circular Economy approach is remanufacturing.

Today, remanufacturing is a key industrial discipline at the end of a product's life cycle. In terms of the economic potential, remanufacturing facilitates multiple use of the value-added from new production by several life cycles. For preserving work, material and energy effort costs of new production can be avoided. Ecologically, this leads to corresponding resource savings and avoiding of emissions as well as waste.

Thus, remanufacturing is cost and resource efficient compared to new production, a fact which has been proven in several studies, e.g. by Köhler in 2011 [5]. Also within the remanufacturing sector competition has increased in the last years. Thus, also remanufacturing operations respectively processes have to become more resource and cost efficient to be able to face the challenges described previously.

The base of process optimization approaches is the process assessment. Watts S. Humphrey described the *assessment* as an important topic to evaluate the own position: “If you don’t know where you are, a map won’t help” [6]. Therefore, the implementation of sustainable measures to improve the resource and cost efficiency needs a reflection of the degree of resource and cost efficiency first. Maturity models enable the target oriented evaluation of operations and processes. In addition to that, maturity models offer a roadmap to integrate improvements. For example, it is possible to compare improved processes against processes assessed previously. Hence, this approach allows to reflect the quality and the success of implemented measures.

In this paper, a maturity model for remanufacturing operations and the results of a process assessment done with the model are shown.

2. State of the Scientific Knowledge and Need for Action

In this section the state of the scientific knowledge and the need for action are described.

2.1. Remanufacturing Operations

The number and sequence of the remanufacturing process steps are depending on the type and functionality of the product. According to Steinhilper, mechanical and electromechanical products have to be separated from mechatronic and electronical products. For mechanical and electromechanical products, five main steps have to be proceeded [7].

According to Freiberger, for mechatronic and electronical products, it is useful to add a sixth step, which is the entrance diagnosis of the product [8]. Thus, failures, which are not based on mechanical wearout, can be identified and the products separated directly. Figure 1 gives an overview of the main process steps of remanufacturing, according to Steinhilper and Freiberger.

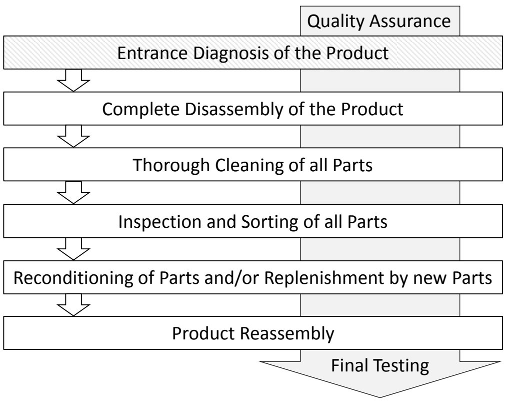

Fig. 1. The process steps of remanufacturing according to [7] and [8].

In the following, the five process steps for mechanical systems according to Steinhilper are described in more detail [Ste99]:

Disassembly

In the first process steps, the old products, termed *cores,* are disassembled completely into their single parts. Parts which cannot be reused or remanufactured are sorted out. The disassembly is mainly done manual, due to different contaminations and degrees of corrosion.

Cleaning

The second process step includes the cleaning, degreasing, deoiling and derusting of all parts, depending of the level and type of contaminations and corrosion. Different cleaning technologies and processes are deployed in sequence or in parallel. The cleaning results are depending on the chemical application time, action of heat, mechanical exposure and process time. To protect the parts and the environment, mainly cleaning processes based on water and steam are used. Furthermore, cleaning processes as shot blasting of glass or steal pearls are used.

Inspection and Sorting

In the third process step, the parts are classified regarding their applicability to be remanufactured respectively to be reconditioned. The parts are classified as following:

- Reusable without reconditioning
- Reusable after reconditioning
- Not reusable / to be replaced

Besides optical inspection procedures, also mechanical and electronical inspection procedures as leak tests, voltage tests or three-dimensional measurements are used. Functional components are inspected regarding their mechanical and / or electronical functionalities also. Unlike in the new production of parts and products, within remanufacturing all parts are inspected to guarantee the required quality.

Reconditioning

Within the next process step, worn out parts are reconditioned by using metal treatment processes as drilling, milling, turning, grinding and honing. Despite the treatment and the consequently changes of the geometry, the differences still stay within the original tolerances or have no influence on the functionality. If the functionally is influenced by changing the geometry, additional process steps as surface treatments would be applied to restore the original geometry. Parts which cannot be reconditioned are replaced with new spare parts.

Reassembly

The fifth step is the reassembly of the parts to a product. The reassembly is done on assembly lines for small batches with the same tools and equipment as applied in the new production. After the reassembly, a functional test of all parts is done to guarantee a 100% quality.

Within remanufacturing operations, the same quality assurance and testing procedures as in the new production are used. In addition to that, remanufacturing products can be updated within the remanufacturing processes. Therefore, remanufactured products have the same or even a better quality than new products.

2.2. Maturity Models

Maturity models conduce to assess enterprises respectively their products, processes or their organization. Furthermore, their degree of maturity concerning certain criteria can be evaluated.

The rudiment of each maturity model is a stage model, which characterizes levels of abilities. By fulfilling defined criteria, the achievement of a higher level of ability and thus a higher level of maturity is attested [1]. The achievement of higher maturity levels guarantees defined, structured and standardized processes [9]. Besides the evaluation result, also a catalog of measures to achieve the next maturity level is shown [1]. Thus, the progress of improvement is made measureable and not only a temporary status. This makes maturity models to an optimal methodology for optimizing processes and strategic positions as well as for benchmarking [1, 10].

The gathering of information for the assessment of the maturity levels is most often done by using questionnaires or check lists. Result of such an assessment is the current maturity (level) of the assessed enterprise [11]. The maturity model assessment is done according to the Plan Do Check Act principle (PDCA) [12].

The selection of an assessment model depends on the financial and personal abilities. In the following, three types of assessments are shown [9]:

- Self-assessment
- Self-assessment with support by external auditors
- Assessment through external assessors

Following, some of the most common maturity models are described.

Capability Maturity Model

The Capability Maturity Model (CMM) was developed by the Software Engineering Institute (SEI) between 1986 and 1991. The development was commissioned by the US Ministry of Defense in order to optimize software processes [9, 13]. The maturity levels are divided into the five steps: Initial, Repeatable, Defined, Managed and Optimized [9]. The application of the CMM is challenging for organization, due to the necessity of using more than one maturity model to assess different departments. Furthermore, the potential of improvement is limited due to the different maturity models used [14].

Capability Maturity Model Integration

The Capability Maturity Model Integration (CMMI) is an advancement of the CMM. The aim of the model is the optimization of whole business processes. The business processes are described by four process categories. 22 process areas are assigned to these categories [14].

European Foundation for Quality Management

As a reaction of high performance requirements in terms of quality, the EFQM Excellence Model was published in 1993 by the European Foundation for Quality Management (EFQM). The framework consists of nine criteria which are subdivided into five enabler criteria and four results criteria. The criteria are divided into 32 sub criteria to which reference points are attached [15, 16].

Software Process Improvement and Capability Determination

The SPICE model (Software Process Improvement and Capability Determination) is documented in the international standard ISO/IEC 15504 [17]. The model has two dimensions, a process dimension, which is divided into five process categories, and a capability dimension [18]. The assessment is carried out based on six capability levels and nine process attributes [17].

2.3. Need for Action

Unfortunately, there is a lack of knowledge when it comes to the assessment of remanufacturing processes, both in research and industry. To close the lack of knowledge, scientists from the Chair Manufacturing and Remanufacturing Technology at the University of Bayreuth and the Fraunhofer Project Group Regenerative Production developed a capability maturity model for remanufacturing operations.

This paper shows a capability maturity model to assess remanufacturing processes and the results of the process assessment of remanufacturing operations, performed by using the maturity model. On the one hand, the capability maturity model will enable remanufacturing companies to benchmark their processes and thus reveal the strength and weaknesses of their processes compared to the processes of other remanufacturing companies. On the other hand, the model will support them to manage the progress of improvement and thus, to improve their cost and resource efficiency.

3. Development of the Maturity Model

In the first step, the indicators which represent the efficiency of remanufacturing operations are defined. Following are the eight indicators to assess the efficiency of remanufacturing operations [19]:

1. Parts management (cores, spare parts and finished products)
2. Technology know how
3. Costs
4. Information flow
5. Material flow
6. Quality management and assurance
7. Technical cleanliness
8. Resource efficiency (sustainability)

In the second step, each first level indicator is specified and described by second level indicators. The first and respective second level indicators can be seen on figure 4 in section *5 Results of the Analysis*.

In figure 2, the structure of the maturity model, including the first and second level indicators as well as the descriptions, can be seen.

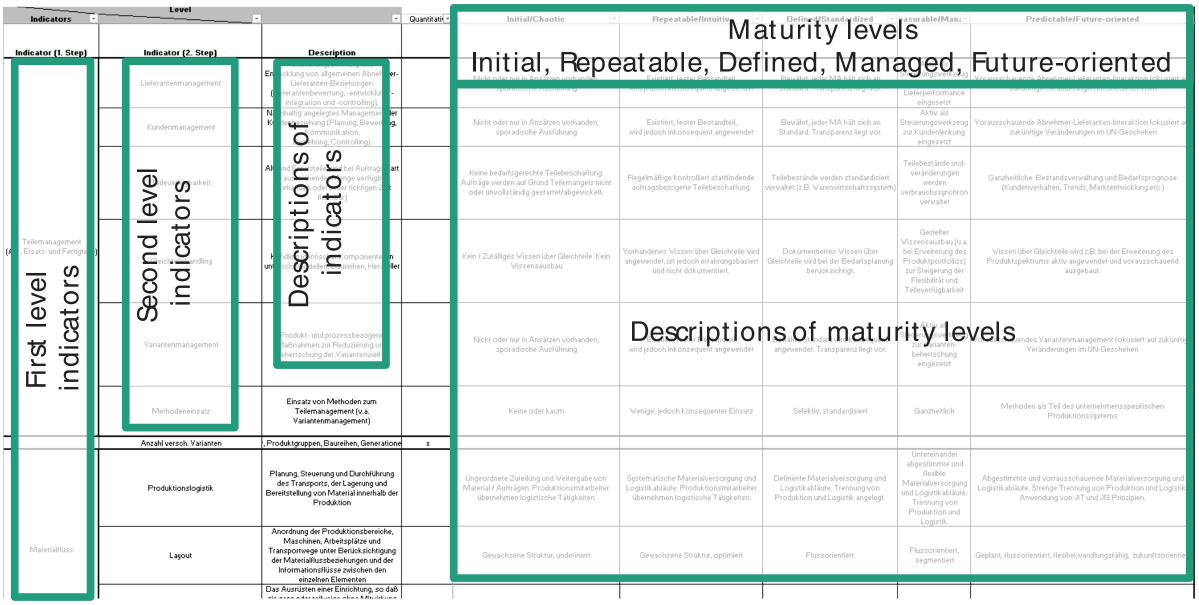

Fig. 2. Structure of the maturity model for remanufacturing operations.

The levels for the maturity model are defined as following:

1. Initial/Chaotic
2. Repeatable/Intuitive

3. Defined/Standardized
4. Managed/Measurable
5. Future-oriented/ Predictable

4. Remanufacturing Process Assessment

The process assessment was executed together with eleven remanufacturing companies across Europe, based on a one to two day visit of the remanufacturing facilities. This means, it was a self-assessment with support by external auditors respectively scientists.

In a first step, a process analysis was conducted, to be able to assess the processes, by using the maturity model for remanufacturing operations. In the second step, an Excel-based questionnaire consisting of 66 questions was edited by the companies' representatives and the scientists. Figure 2 shows an extract of the questionnaire.

5.2 Analysis of Technical Cleanliness

Know how and technical equipment to analyse technical cleanliness.

Question 5.2.1	1	2	3	4	5
How would you rate the know how in your company to analyse technical cleanliness?	No/random know how to analyse technical cleanliness. No gain of know how.	Know how to analyse technical cleanliness is available but experience based and not documented.	Know how to analyse technical cleanliness is available and documented.	Know how to analyse technical cleanliness is sufficient and documented, regularly validated, improved and extended.	Know how to analyse technical cleanliness is sufficient and documented, regularly foresighted validation, improved and extended to gain an advance in knowledge.
Answer					

Fig. 3. Extract of the questionnaire to assess remanufacturing operations.

This approach ensures the best results in terms of neutrality, due to the external auditors, and the best results in terms of quality of the answers, due to the involvement of the representatives of the remanufacturing companies. Furthermore, it was possible to use the process assessment to collect information about the usability of the maturity model for remanufacturing operations, respectively about the usability of the questionnaire.

The results of the assessment where provided to the company, which enables them to optimize their remanufacturing operations.

5. Results of the Analysis

After the assessment of the eleven remanufacturing companies, the results were condensed in the Excel-based tool. The following table shows a summarization of the gathered information.

Table 1. Summarization of the remanufacturing processes assessment.

First Level Indicators	Average Maturity Level	Second Level Indicators	Average Maturity Level
Parts Management (Used, Spare and Finished Parts)	2.4	Supplier Management	2.5
		Customer Management	2.6
		Parts Availability	2.8
		Common Parts Handling	2.3
		Variant Management	2.2
		Application of Methods	2.0
Material Flow	2.2	Production Logistics	2.5
		Layout	2.6

		Automation	1.3
		Application of Methods	1.9
		Average Lot Size	3.6
Information Flow	2.7	Information Transfer	2.8
		Production Planning and Control (PPC)	2.6
		Transparency	2.8
		PPC System	2.9
		Performance Indicators	2.9
		Application of Methods	1.8
Quality Management / Quality Assurance	2.7	Certifications	2.3
		Product Quality	3.3
		Process Quality	3.2
		Quality of Used Parts	2.6
		Application of Methods	2.3
Technical Cleanliness	1.8	Generating Technical Cleanliness	2.1
		Analysis of Technical Cleanliness	1.8
		Prevention of Technical Cleanliness	2.3
		Application of Methods	1.3
Resource Efficiency (Sustainability)	2.1	Material Efficiency	2.3
		Energy Efficiency	1.5
		Waste / Environmental Management	2.5
		Industrial Safety / Ergonomics	2.8
		Application of Methods	1.5
Technology Know How	2.5	Product know how	2.8
		Process know how	2.5
		Employee Qualification	2.7
		Knowledge Management	2.1
		Product Modification	2.4
Costs	2.6	Cost Accounting / Cost Orientation	3.3
		Cost Transparency	2.3
		Application of Methods	2.2
Total	**19.0**		

As an overall result, the eleven remanufacturing companies had an average of 19 out of 40 possible points within the maturity model. That means, there is still a lot of potential for improvement.

The biggest potential for improvement within the first level indicators is the technical cleanliness. The biggest potentials for improvement within the second level indicators are, the degree of automation within the indicator material flow, the energy efficiency as well as the application of methods within the indicator resource efficiency, and the application of methods within the indicator technical cleanliness, followed by the application of methods within the indicators material flow and information flow.

6. Conclusion and Outlook

This paper shows a capability maturity model to assess remanufacturing processes, and the results of the process assessment of remanufacturing operations, generated by using the capability maturity model.

The research results can be used by other researchers for deeper analysis of remanufacturing operations and processes as well as a base for developing measures to improve remanufacturing operations respectively processes.

Furthermore the results, especially the Excel-based tool, can be used by remanufacturing companies to assess their remanufacturing operations respectively processes, to manage their improvement process, and to benchmark their processes against other companies' processes. At the end of the day, the results will support the remanufacturing industry to assess and to improve their operations, in terms of ecological and economical aspects.

In future research, a web tool will be developed, based on the research results and the Excel-based tool described. This web tool will enable online assessments, whereby the users will get the assessment results directly after finishing the questionnaire. On the one hand, a web tool enables more people to use the research results and on the other hand, a web tool will enable researchers to collect more data from remanufacturing companies. Besides the collection of data, the focus of the web tool will be dynamic thresholds of the indicators. This will be the base for a web tool which is self-updating its database, continuously.

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