Managing Complexity in Remanufacturing Focusing on Production Organisation

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Abstract
Due to individual requirements of economic actors, remanufacturing companies face the challenge of an increasing variety as well as the associated complexity. Therefore, a successful complexity management, created upon detailed knowledge of drivers and effects, is necessary. To close the lack of knowledge, the main complexity drivers and effects within the production organisation of remanufacturing companies are identified. Furthermore, common optimisation methods to manage this drivers and effects are assessed and the best ranked methods are shown within this paper. For the complexity effects, which occur the most and with a low number of available optimisation methods, new methods are presented.

Keywords:
Remanufacturing; Complexity Management; Production Organisation

1 INTRODUCTION

The individual requirements of economic actors lead to an increased variety in products and services. With every new variant, the effort of manufacturing increases. Thereby, the level of additional effort depends directly on the occurring complexity of the respective process. This process complexity is further co-determined by the number of variants of the products which have to be produced [1]. Additionally the resource efficient usage of capacities and the demand for minimum emission in the manufacturing of goods contributes to an increased process complexity.

Remanufacturing companies face similar challenges as companies from other industrial sectors. One challenge is the high variety due to the broad spectrum of Original Equipment (OE) brands (e.g., Bosch and Delphi), product groups (e.g., engines and alternators), generations (e.g., VW Golf 3, 4 and 5), configurations and varying core quality (e.g., degree of contamination and degree of wear or usage history) [2]. Compared to manufacturers of new parts, companies of the industrial sector of remanufacturing can only react passively to an increased complexity in products and processes instead of an active avoidance or reduction [1] [2]. For this reason a successful complexity management, based on detailed knowledge of complexity drivers, effects and optimisation methods is necessary.

Therefore, the project results of the quantification of complexity drivers and effects as well as of optimisation methods focusing the production organisation in remanufacturing companies are considered. Furthermore, new optimisation methods are presented in the course of this paper.

2 STATE OF THE SCIENTIFIC KNOWLEDGE AND NEED FOR ACTION

2.1 Remanufacturing

Remanufacturing is the industrial process to restore used products to an "as good as new" condition [3] [4] [5]. The worldwide remanufacturing industry represents about 100,000 companies with a turnover of approximately 100 billion Euros [2] [3]. The remanufacturing process of mechanical products can be divided into five main process steps (Figure 1) [6].

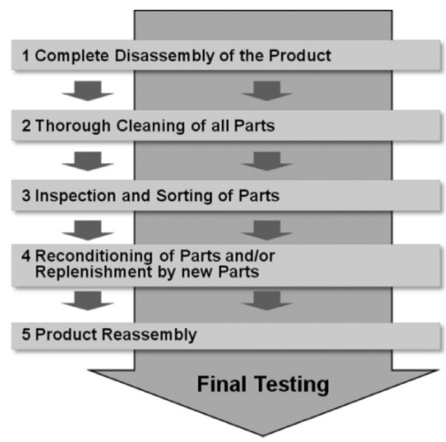

Figure 1: Main steps in the remanufacturing process [6].

2.2 Complexity

According to Ulrich and Probst [7], complexity is a system quality whose degree depends on the number of system elements, the plurality of the connections between these elements and the number of possible system states. In general, three main management strategies to manage the negative effects of complexity can be distinguished: avoid complexity, reduce complexity and handle complexity [2] [8].

2.3 Need for Action

Studies show that costs which are related to product and process complexity can make up to 25 percent of the total costs in manufacturing companies [8]. Progress regarding complexity reduction can be identified to a greater extent in the field of logistics, supply chain management and production techniques [9] [10]. Approaches for managing complexity specific to the needs of the remanufacturing industry do not exist so far [11].

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In their study “Industrial Challenges within the Remanufacturing System” Lundmark and Sundin found out that uncertainty and complexity are some of the most challenging factors in remanufacturing which have to be faced in the future [4].

Therefore, within the European research project reCORE (research for efficient configurations of remanufacturing enterprises), which is founded by the German Federal Ministry of Economics and Technology, scientists at the University of Bayreuth are searching for solutions to manage complexity in the remanufacturing industry.

2.4 Research Methodology

All shown results, except the new optimisation methods, have been determined within an empirical approach. The necessary data were collected by analysing company data and by questionnaires. The evaluation and validation of the results and solutions were done by expert interviews and workshops. The methodology to systematically identify, analyse and evaluate complexity drivers and effects as well as optimisation methods has already been presented in detail on the Swedish Production Symposium 2012 [11].

This paper shows the results of quantifying complexity drivers and effects, which can occur within the production organisation of remanufacturing companies, as well as the applicability of common optimisation methods to handle these drivers and effects. Furthermore new optimisation methods, which were developed within the research project reCORE to handle complexity, are presented.

3 ANALYSIS AND EVALUATION OF COMPLEXITY IN REMANUFACTURING FOCUSING PRODUCTION ORGANISATION

In the field of production organisation 26 drivers and 50 effects were identified, which leads to an evaluation of 1.300 combinations. The quantification of the drivers and effects allows the identification of the main drivers and effects and serve as a basis to derive a suitable complexity management. The top ten drivers in the field of production organisation are shown in Figure 2. The top ten effects within the production organisation are shown in Figure 3.

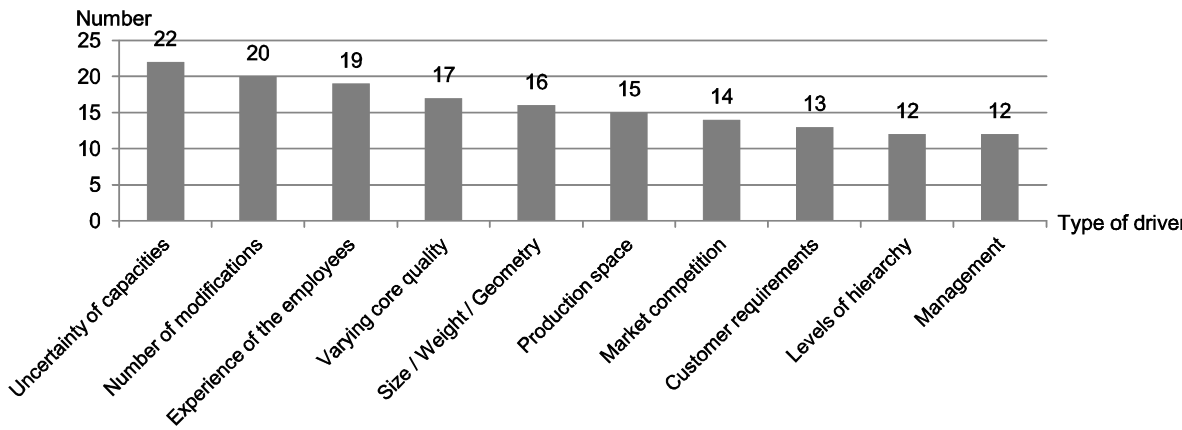

Figure 2: The top ten complexity drivers influencing production organisation in the field of remanufacturing.

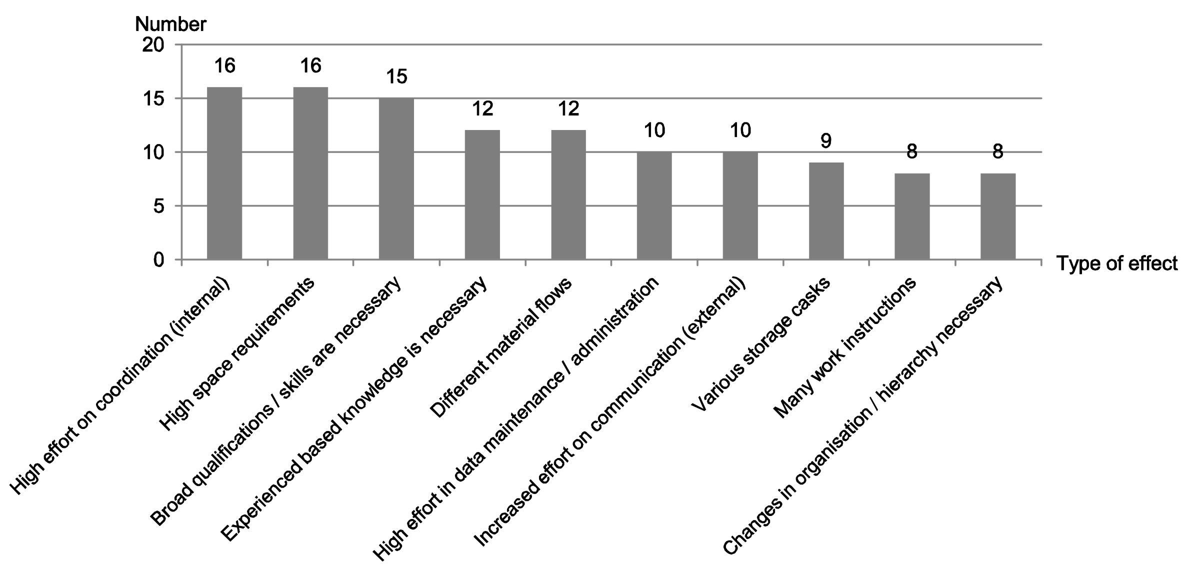

Figure 3: The top ten complexity effects influencing production organisation in the field of remanufacturing.

The chart shown in Figure 2 indicates that “Uncertainty of capacities” and “Varying experience of employees” as internal complexity drivers as well as “Number of Modifications” and “Varying core quality” as external complexity drivers cause the majority of the effects.

The chart shown in Figure 3 indicates that for a total consideration of the results within the production organisation, the effects “High effort on coordination (internal)” and “High spare requirements” with 16-fold occurrence each as well as “Broad qualification/skills necessary” with 15-fold occurrence and “Experience based knowledge necessary” with 12-fold occurrence represent a high proportion compared to the other effects turning up.

4 ANALYSIS AND EVALUATION OF OPTIMISATION METHODS

Besides the knowledge about complexity drivers and effects, remanufacturing companies also need suitable methods and tools to manage the complexity effects. Therefore 46 common optimisation methods are identified and assessed to each complexity effect. As mentioned before, for the assessment of drivers and effects a discrete evaluation was carried out for each combination of effect and optimisation method (or tool). The assessment evaluates whether a method is suitable or not to manage a complexity effect.

The top ten methods in the field of production organisation are shown in Figure 4. According to the results of the analysis, “Standardisation”, “Production planning and control (PPC)”, “Visualisation” and “Supplier management” are the top ranked optimisation methods to manage complexity in remanufacturing companies in the field of production organisation.

The results of this analysis are used to highlight the top optimisation methods as well as to detect gaps of available methods and thus to identify the need for further development.

Effects	occurrence *(Number)*	applicable methods *(Number)*
High effort on coordination (internal)	16	12
High space requirements	16	10
Broad qualifications/skills necessary	15	5
Experienced based knowledge necessary	12	5
Different material flows	12	12
High effort in data maintenance/administration	10	7
Increased effort on communication (external)	10	6
Various storage casks	9	4
Many work instructions	8	10
Changes in organisation/hierarchy necessary	8	5

Table 1: Number of applicable optimisation methods.

In Table 1, the numbers of optimisation methods which are applicable to the top ten complexity effects are shown. For the effect “High effort on coordination (internal)” a broad spectrum of optimisation methods is available whereas for the effects “Broad qualifications/skills necessary” and “Experienced based knowledge necessary” only five methods each are available. Hence for the complexity effects with a low number of available optimisation methods and on the basis of expert interviews, new optimisation methods, suitable for the production organisation of remanufacturing companies, were elaborated. A selection of the newly developed methods is presented in the following.

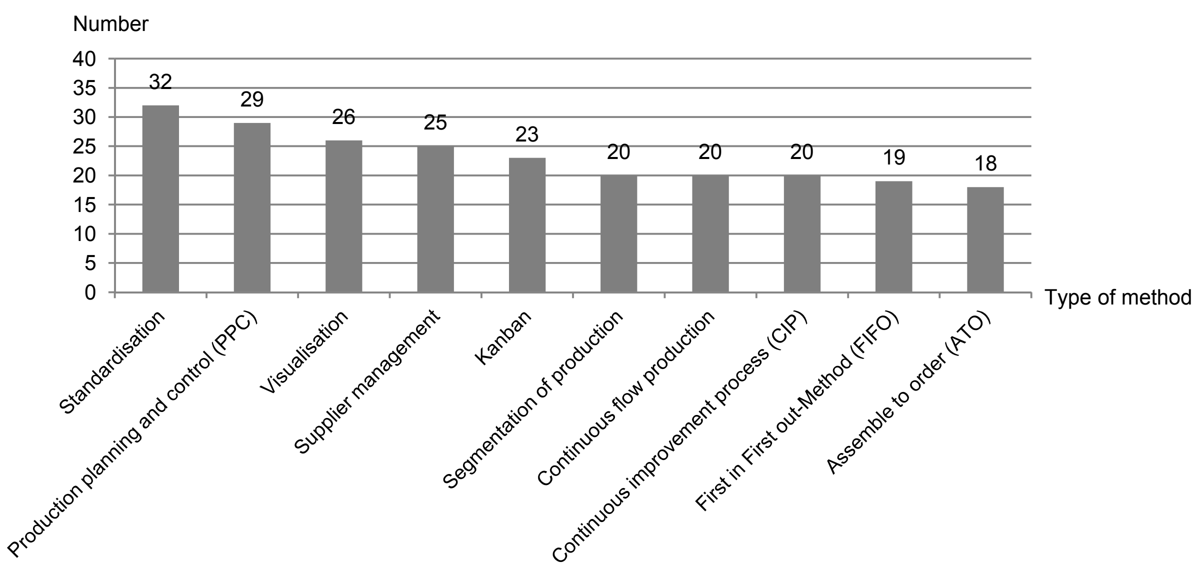

Figure 4: The top ten methods for managing complexity in production organisation in the field of remanufacturing.

5 DEVELOPED OPTIMISATION METHODS

5.1 Employee Knowledge Balanced Chart

As Figure 2 shows, the driver "Experience of employees" is one of the highest rated complexity drivers. This means that especially the employees are an influencing factor for the complexity.

Increasing work contents, strongly varying tasks and advancing expert knowledge are only the most important trends related to the employees in the production. In order to stay competitive the production staff must face this complexity by achieving a high degree of flexibility. This higher degree of flexibility can reached by a high level of expertise in as many job contents as possible.

In this case the job of the production management is to lead the staff to a high degree of flexibility by controlling the knowledge of the employees. Due to the fact that the most firm-specific knowledge and skills are only held in the minds of the employees, who are using this knowledge during their daily work, the production management can only have a supportive role.

For a highly efficient increase of the staff's knowledge and skills the method of the Employee Knowledge Balanced Chart was developed. The basic idea of this method is to give the production management an overview of the existing knowledge and skills of every employee of a department. Moreover, in contrast to well established methods like the qualification matrix, the Employee Knowledge Balanced Chart not only illustrates lacks of knowledge but also reveals potentials for synergies. This employee information is presented in the form of a single chart (Figure 5).

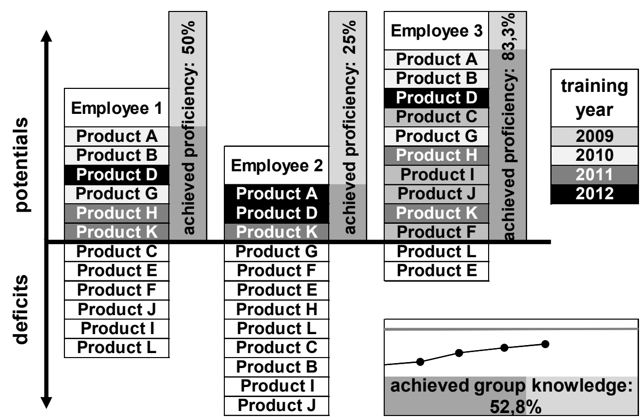

Figure 5: Example of an Employee Knowledge Balanced Chart.

In order to implement and work with the Employee Knowledge Balanced Chart in the production, the following five steps are necessary:

1. Collection of data: In the first step data about the existing knowledge and skills of every employee need to be collected. This can be done by interviewing the employees or if possible by a perusal of qualification documents. To prevent wrong or aged data this step should be done in close cooperation with the concerned employees.
2. Creation of the graphical representation: The existing knowledge and skills of each employee need to be depicted by using a diagrammatic representation for each department. A horizontal line separates the potentials and the deficits. For a better overview and to detect necessities of refreshment it is useful to colourise the existing fields of knowledge and skills whereby the colour represents the year in which the qualification was achieved. Afterwards the ratio of potentials and deficits can be added as a key performance indicator for each employee (achieved proficiency) and of course as well for a whole group or department (achieved group knowledge).
3. Decision about the needs for trainings: The complete representation of the Employee Knowledge Balanced Chart offers an overview of the deficits and potentials of every staff member. To act as efficiently as possible the most prevalent deficits should be focused in future trainings.
4. Training of the employees: The focused knowledge and skills are trained to the affected employees. The training should be given by employees, who already have experience in the relevant field and therefore serve as a multiplier. These experienced staff members can be detected by using the Employee Knowledge Balanced Chart. In order to verify the training success it is necessary to finish this step with a test, such as an independent and accurate proceeding in the trained field under supervision of the experienced employee.
5. Update of the Employee Knowledge Balanced Chart: In this step the achieved qualifications are cleared from the deficits and added to the potentials.

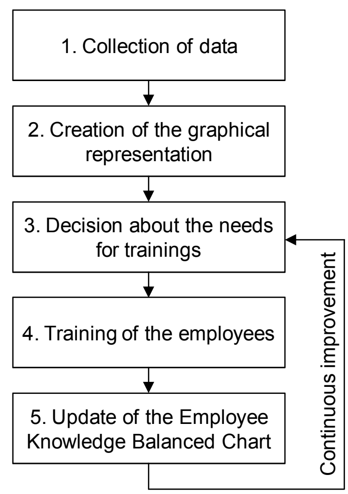

Figure 6: Procedure of the Employee Knowledge Balanced Chart.

To ensure a continuous improvement process it is advisable to return to step 3 ("Decision about the needs for training") after a successful treatment of step 5 ("Update of the Employee Knowledge Balanced Chart"). Figure 6 shows the procedure of the implementation of the Employee Knowledge Balanced Chart.

This continually recurring process can be repeated until a desired level of existing knowledge and skills is achieved. After reaching this high level of flexibility by a broad range of knowledge and skills of the staff it is recommendable to resume the repetitive process. But during the treatment of step 3 ("Decision about the needs for training") the management has to focus on the trainings with the oldest dates. This proceeding has the background of a continuous refreshment of knowledge and skills.

The diagrammatic presentation of the Employee Knowledge Balanced Chart provides an overview of the existing potentials and deficits of knowledge and skills. Due to this overview the production management and the employees are able to increase knowledge and skills in a high efficient way. Furthermore the targeted selection of trainings leads to decreasing training costs.

The inclusion of key performance indicators helps the production management to define objectives in close cooperation with the staff members. Due to the ambition of the employees to achieve the defined objectives the motivation to increase the knowledge and skills raises and also the company loyalty of the staff is improving.

In addition, the production management is able to detect less experienced employees and assist them to achieve a higher level of knowledge and skills. This can be used for restructuring measures like job enlargement which also improves the responsiveness to peaks of workload and work stoppages [12] and therefore positively influences the top complexity driver “Uncertainty of capacities”.

Moreover, this method deals with different top ten complexity effects like the necessity of broad qualifications and skills as well as experience based knowledge.

In summary, the use of an Employee Knowledge Balanced Chart leads to a high degree of flexibility. This high degree of flexibility enhances the reactivity in the field of the production whereby the competiveness maximises.

5.2 Agile Production Area

Nowadays production must be able to handle highly volatile changes. As illustrated before, some of the most named complexity effects in the production organisation are high space requirements and different material flows. The following presented method was developed to manage these complexity effects. Most production areas are in operation with the same arrangement since many years. This means that the layout of the shop floor was also created many years ago. Due to the fact that the production is exposed to highly volatile changes, the conditions, which were existent during the set up of the consisting shop floor layout, became obsolete.

Usually the production management tries to increase the efficiency of the production by initiating changes. Practice, however, shows that only slight changes are usual. Due to the aspiration to keep the effort small the efficiency of the production is only improving with small steps.

However a general change would lead to an optimum of the production efficiency. Nevertheless the general realignment needs a high planning effort and due to the highly volatile change the implementation effort became obsolete after only a short time.

This means that a rapid change and adjustment of the production area must be possible with the lowest amount of planning and implementation effort.

The described method was developed to achieve a rapid change and adjustment with the lowest amount of time and effort. The method of the Agile Production Area deals with the intelligent arrangement of the production resources. According to Gienke and Kämpf the resources in the field of the production are personnel, equipment, materials, time and information [13]. Primarily this method deals with the personnel, equipment and materials. For achieving a rapid change and adjustment it is very important that the used equipment and materials are movable or can be made movable (e.g., by using wheels for a better mobility). Suitable areas in remanufacturing companies are for example the disassembly area, the inspection area and the reassembly area as usually no heavy machinery has to be moved in this area.

The procedure of the Agile Production Area has the following steps:

1. Development of the algorithm**:** First of all an algorithm must be developed. This algorithm must be able to generate an ideal layout by taking the forecasted work orders and the existing employee attendance into regard. Available equipment and material resources must be stored in a database. Beneath these functionalities the algorithm should consider several constraints like unmovable resources as well as the ratio of benefit and effort.
2. Update of the work list: The work list which contains information about the future work orders must be up to date.
3. Update of the attendance list**:** Besides the work list, it is necessary to maintain a list containing the current available employees.
4. Generation of the layout: In this step the updated work list and the updated attendance list are the input for the algorithm for generating the layout with the most efficiency for the upcoming conditions of production.
5. Arrangement of the resources: The employees have to implement the generated layout. Due to the movable equipment and materials it should be possible to do this step in a short time. Unused equipment and materials can be stored in an intended area.
6. Check of the arrangement: After the resources are in place it is important to check the completeness and the optimum of the arrangement. Small improvements can be done before the production starts.

After the steps are worked through the production is able to start with the work order. Figure 7 shows an overview of the procedure.

The production management has to take into account, that step 5 ("Arrangement of the resources") and the step 6 ("Check of the arrangement") are causing downtimes, which are required during the procedure of the Agile Production Area.

After the work order is finished, the production area can be rearranged. In this case the procedure starts with step 2 ("Update of the work list"). Due to the recurring process a permanent adaption of the production area is guaranteed.

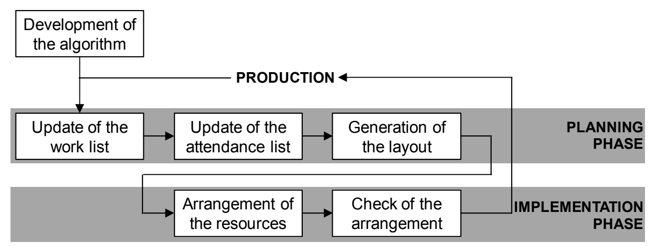

Figure 7: Procedure of the Agile Production Area.

The primary benefit of the introduction of this method is a quick adaption to high volatile changing conditions in a most efficient way. Because of the high efficiency in the production the cycle times as well as non-productive times for material handling and transportation are kept as small as possible. This leads to a reduction of the production costs.

Furthermore, as only necessary resources are available to the employees, the risk of failures caused by the use of wrong resources (e.g., incorrect tools and false material) decreases. This leads to an improved quality of the products and a reduction of the complaint rate.

5.3 Core Quality Oriented Supply Chain

The above presented results (Figures 2 and 3) show that for remanufacturing companies the varying core quality is one of the highest rated complexity drivers. Core is the international term for an old unit or used product [6]. The core quality depends on different factors (e.g., degree of contamination, reusability and completeness). This variety of core quality leads to an increasing complexity for the remanufacturing company.

Instead of checking the quality of the core at the beginning of the remanufacturing process the method of the Core Quality Oriented

Supply Chain recommends to source out the core quality check. Due to the fact that the cores are usually collected from different suppliers (e.g., Original Equipment Manufacturers (OEMs), core dealers, customers and recycling companies), it is very costly and time consuming for remanufacturers to subject incoming cores to an additional quality check.

The Core Quality Oriented Supply Chain suggests that the remanufacturer purchases the cores from a key supplier. This key supplier collects the cores from different suppliers and has to ensure a quality check and a presorting of different core qualities. Figure 8 shows the Core Quality Oriented Supply Chain with the key supplier between the different suppliers and the remanufacturer. This method manages not only the complexity, it also reduces the complexity.

The risk of the implementation of this method is the loss of knowhow to the key supplier.

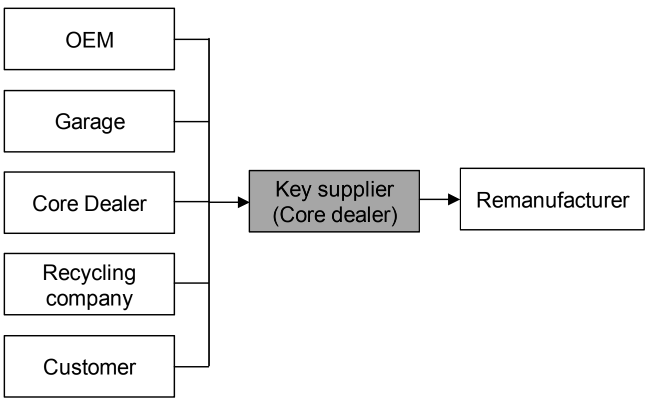

Figure 8: Core Quality Oriented Supply Chain.

The method of the Core Quality Oriented Supply Chain has different benefits:

- Unusable cores are scrapped previously in the supply chain.
- The effort which is caused by bad and variable core quality can be reduced.
- Downstreamed processes can be planned in a better way because of the stable core quality.
- Resources can be used to capacity, therefore dates and deadlines can be complied.
- The effort for communication (external) can be reduced.
- The core warehouse can be downsized, which also reduces the capital commitment.

6 SUMMARY

This paper shows for the first time the main complexity drivers and effects occurring in the production organisation of remanufacturing companies. The analysis and the newly developed optimisation methods enable the remanufacturing industry establishing a suitable complexity management. The implementation of the presented methods in remanufacturing companies enables them to reduce complexity (Core Quality Oriented Supply Chain) and/or to handle complexity (Employee Knowledge Balanced Chart, Agile Production Area).

As part of future research the presented optimisation methods will be verified by pilot trials.

Furthermore, it would be interesting to analyse the costs of complexity in remanufacturing to make complexity drivers and effects as well as optimisation methods monetarily assessable.

7 ACKNOWLEDGMENTS

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