

Industry Sector Specific Remanufacturing Processes

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Abstract

Today, remanufacturing is a key industrial discipline at the end of a product's life or use cycle. In terms of the economic potential, remanufacturing facilitates multiple use of the added value from new production by several life cycles. For preserving work, material and energy effort costs of the new production can be avoided. Ecologically, this leads to corresponding resource savings as well as avoidance of emissions and waste. Unfortunately, there is a lack of knowledge, both in industry and science, when it comes to an understanding of industry sector specific remanufacturing processes. Therefore, scientists from Bayreuth analyzed remanufacturing companies across Europe. The paper shows the main results of the study. At the end of the day, the paper supports the remanufacturing industry by creating a better understanding of remanufacturing processes in different industry sectors.

Keywords: Remanufacturing; Industry Sector Specifics; Processes

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Introduction

Due to increasing competitive constraints, the corporate landscape has changed in the recent years [1]. Furthermore, the profitability of enterprises are endangered due to increasing resource scarcity and increasing commodity prices [2]. A system changing approach to face these challenges is the *circular economy*.

The circular economy aims to “close the loop” of product life cycles through recycling and re-use. Europe’s transition towards a circular economy will boost global competitiveness, foster sustainable economic growth and generate new jobs. [3] The overall idea of the circular economy is illustrated by the Ellen MacArthur Foundation (EMF) in their circular economy system diagram [4].

One key element of the circular economy is remanufacturing. Today, remanufacturing is a key industrial discipline at the end of a product’s life or use cycle. Remanufacturing is performed due to economic, ecological and / or policy reasons [5].

Hauser and Lund describe remanufacturing as the process to restore nonfunctioning, discarded or traded-in products to a condition as new [6]. Also according to Nasr and Thurston, the condition of remanufactured products is “as-new” [7].

Figure 1 illustrates the remanufacturing system, according to Östlin [8].

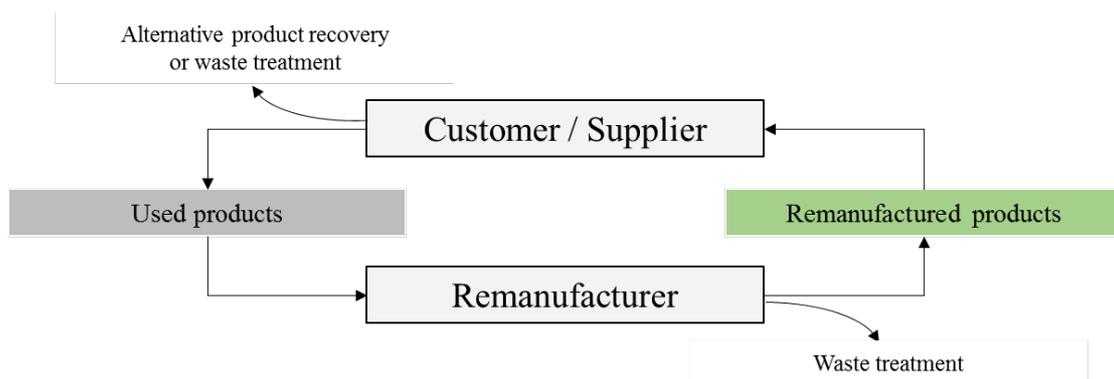


Figure 1: The remanufacturing system. Modified from: Östlin [8].

Used products are collected by suppliers, e.g. garages, and sent to a remanufacturing company via the reverse supply chain. After the remanufacturing process, the remanufactured product is distributed via the forward supply chain.

The ecological and economic advantages of remanufacturing have been shown in many studies, e.g. by Köhler [9] and Kara [10]. Sundin and Lee have condensed studies which show the ecological and economic advantages of remanufacturing in a paper in 2012 [11].

State of the Scientific Knowledge and Need for Action

Remanufacturing is performed in many industry sectors, e.g automotive, rail and heavy duty industry. Depending on the industry sector, the number and sequence of the remanufacturing process steps may vary.

According to Steinhilper, mechanical and electromechanical products have to be separated from mechatronic products. For mechanical products five main steps have to be proceeded. [12]

According to Freiberger, it is useful to add the entrance diagnosis of the product as a sixth step, for mechatronic and electronical products. Thus, failures which are not based on mechanical wear out can be identified directly [13].

The five respectively six process steps of remanufacturing according to Steinhilper and Freiberger are illustrated in figure 2.

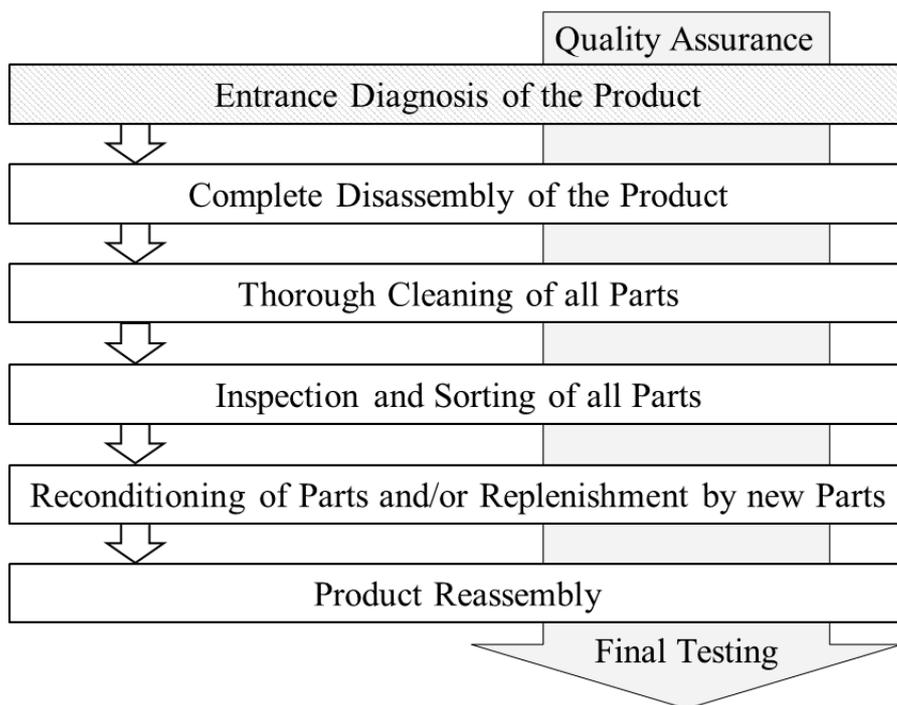


Figure 2: The process steps of remanufacturing according to Steinhilper [12] and Freiberger [13].

In the following, the five process steps for mechanical systems according to Steinhilper are described in more detail [12].

Disassembly

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 variety of contaminations and different degrees of corrosion.

Cleaning

The cleaning step includes the degreasing, deoiling and derusting of the parts. 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.

Inspection and Sorting

The parts are classified regarding their applicability to be remanufactured respectively to be reconditioned. The parts can be classified e.g. 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 applied. Functional components are inspected regarding their mechanical and / or electronical functionalities also. Unlike in the new production of parts and products, within remanufacturing normally all parts are inspected.

Reconditioning

Worn out parts are reconditioned by using metal treatment processes e.g. as drilling, milling and grinding. 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 functionality is influenced by changing the geometry, additional process steps as surface treatments are applied to restore the original geometry. Parts which cannot be reconditioned are replaced by new spare parts.

Reassembly

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 performed to guarantee a 100 per cent quality.

Within remanufacturing operations, the same quality assurance and testing procedures as in the new production are deployed. In addition to that, remanufacturing products can be updated within the remanufacturing processes.

Besides the above mentioned descriptions of remanufacturing process steps, there is a lack of knowledge when it comes to the understanding of industry sector specific remanufacturing processes. Therefore, scientists from the University of Bayreuth have analyzed remanufacturing processes, performed within remanufacturing companies across Europe.

The study has two aims. The first aim is to analyse the industry sector specific remanufacturing processes. The second aim is to identify similarities and differences between the industry sectors regarding their specific remanufacturing processes. The main results of the study are shown in this paper.

The overall goal of the study is to support the remanufacturing industry by providing a base for cross sectoral learning.

Methodology

In the first step, the scope of the study was defined. The scope of the industry sectors covered within the study is based on the importance of the industry sectors within Europe, in terms of significance of remanufacturing activities.

Therefore, the following nine industry sectors are covered within the study [14]:

- Automotive industry
- Consumer goods / Electronic products industry
- Machinery industry
- Heavy duty / off road equipment industry
- Medical equipment industry
- Aerospace industry
- Marine industry
- Furniture industry
- Rail industry

In the second step, a questionnaire was designed and send to remanufacturing companies across Europe. The question related to remanufacturing processes was designed as an open question. Therefore, the participants were asked to describe the remanufacturing processes, performed in their company, in their own words. Thus, the participants were not influenced by any predefined reply possibilities. The study about remanufacturing processes was conducted as part of the remanufacturing market study, which was done within the EC-funded project ERN – European Remanufacturing Network [14]. This approach yielded 105 responses mainly from remanufacturing companies across Europe. Besides the open question about the remanufacturing processes, the participants had to choose, in which industry sectors their remanufacturing activities take place. Some of the companies are active in more than one industry sector, e.g. automotive and marine industry. Therefore, 144 indications were made by the 105 participants. Thus, the coverage factor is 1.37.

Figure 3, 4 and 5 provide and impression of the companies which have participated in the study.

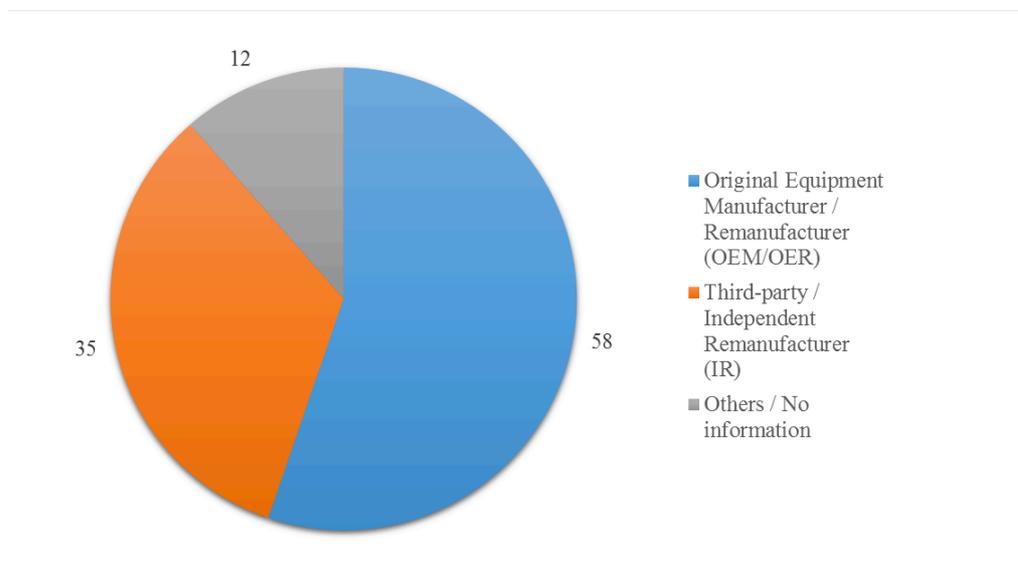


Figure 3: Number of responses sorted by the business model.

In figure 3, it is illustrated that the participating companies are mainly Original Equipment Manufacturers (OEMs) or Original Equipment Suppliers (OESs) followed by Third-party or Independent remanufacturers (IR). 12 of 105 participating companies have a different business model or did not specify their business model.

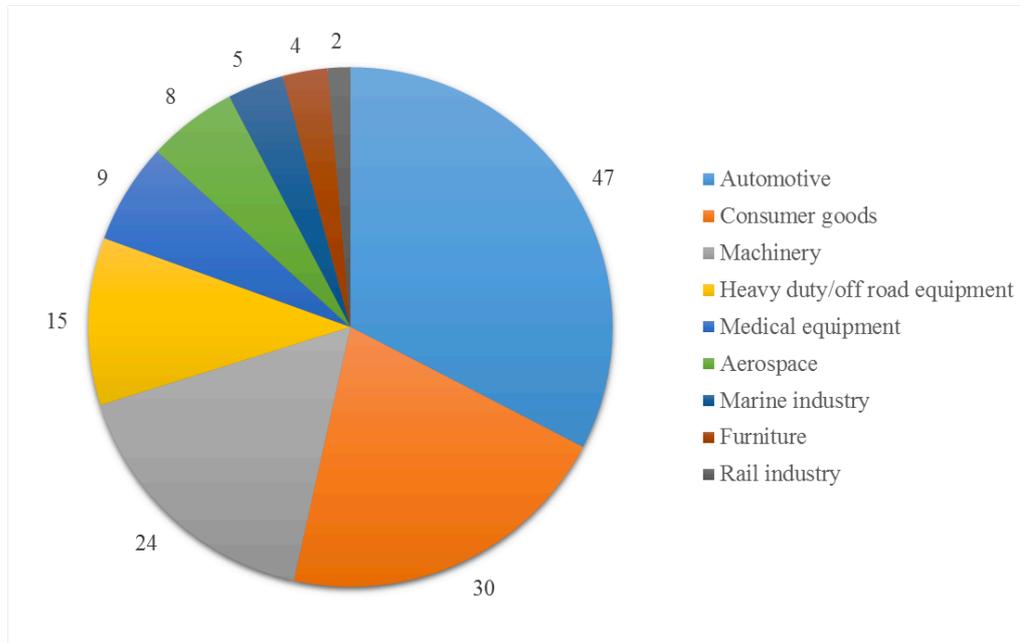


Figure 4: Number of responses sorted by the industry sectors.

Figure 4 illustrates the distribution of the participants by their industry sector. The automotive industry sector is the most mentioned industry sector with 47 indications followed by the consumer goods industry sector with 30 indications and the heavy duty / off road equipment industry sectors with 15 indications.

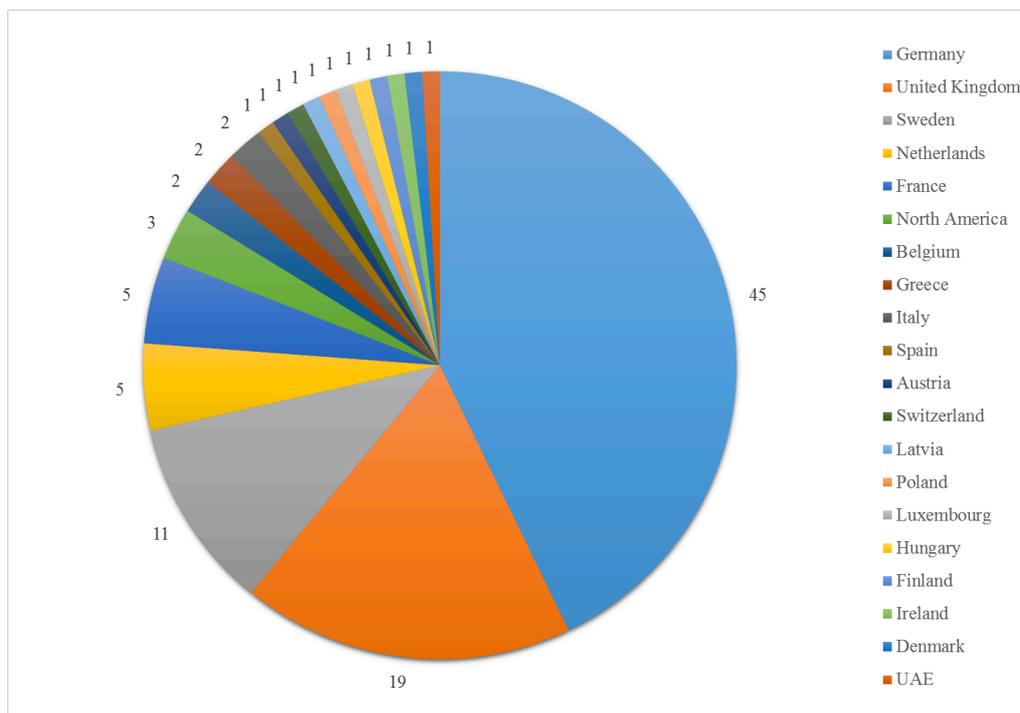


Figure 5: Number of responses sorted by countries (headquarter).

In figure 5, the participating companies are illustrated, sorted by the country of the headquarters. Most of the companies have their headquarter in Germany, followed by the United Kingdom and Sweden.

In the third step, the data were analyzed. Due to the open question asked, within the questionnaire, the data received had to be normalized. That was done in a three-step approach. In the first steps, the process descriptions were analyzed and the terms of the generic process steps described were noted. In the second step, the descriptions indicated the most, were identified. The following eleven generic process steps were identified:

1. Incoming Inspection
2. Disassembly
3. Cleaning
4. Inspection
5. Reconditioning
6. Replace of worn parts with new ones
7. Erase Data
8. Software Installation
9. Consumables Refill
10. Reassembly
11. Final Check

In the third step, all process descriptions were normalized due to the defined descriptions. For example, the text “We have to test and disassemble the parts before we clean them...” was normalized to the following process description and order: Incoming inspection, disassembly, cleaning. Thus, it was possible to aggregate the data gathered.

Results

In this chapter, the main results of the study are presented.

Figure 6 illustrates the distribution of the generic process steps performed in the 105 participating remanufacturing companies.

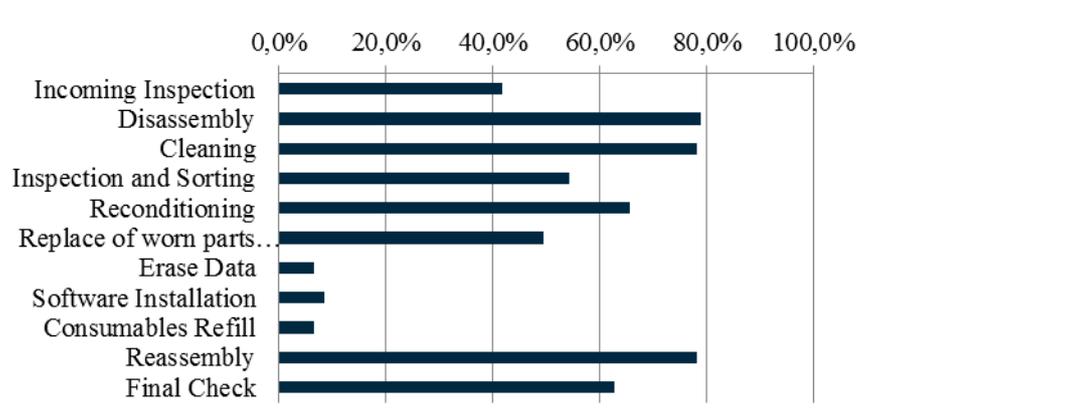


Figure 6: Distribution of generic remanufacturing process steps in remanufacturing.

The generic process steps *disassembling*, *cleaning* and *reassembly* are performed in nearly 80 per cent of the companies. The generic process steps *disassembly*, *cleaning*, *reconditioning*, *reassembly* and *final check* are performed at 60 per cent of the

companies, at least. The generic process steps Erase data, software installation and consumable refill aren't performed in more than 10 per cent of the companies. Following, the distribution of the generic process steps for each of the analyzed industry sectors are shown.

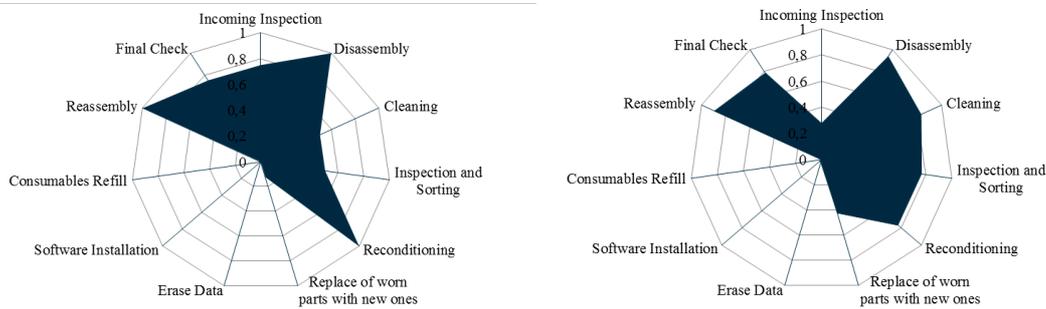


Figure 7: Generic remanufacturing process steps in the aerospace industry (left chart) and the automotive industry (right chart).

The generic process steps, which are performed in at least 60 per cent of the companies in the aerospace industry are: *Incoming inspection, disassembly, reconditioning, reassembly and final check.*

In the automotive industry, the generic process steps, which are performed in at least 60 per cent of the companies, are: *Disassembly, cleaning, inspection and sorting, reconditioning, reassembly and final check.*

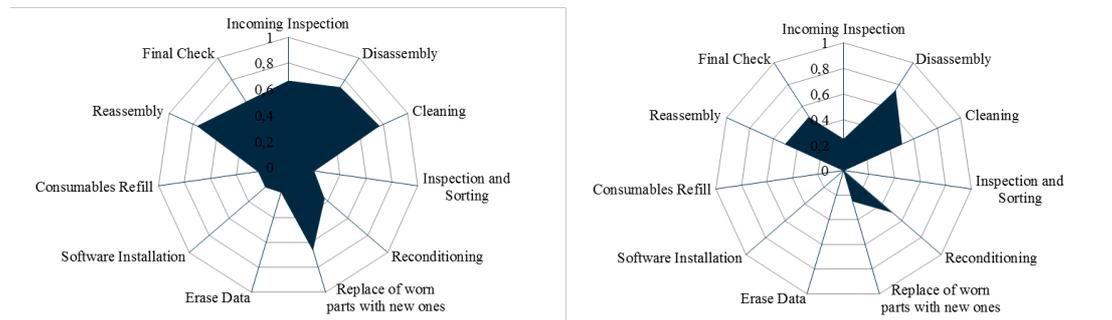


Figure 8: Generic remanufacturing process steps in the consumer goods industry (left chart) and the furniture industry (right chart).

In the consumer goods industry, the generic process steps, which are performed in at least 60 per cent of the companies, are: *Incoming inspection, disassembly, cleaning, replace of worn parts with new ones, reassembly and final check.* The generic process steps, which are performed in at least 50 per cent of the companies in the furniture industry are: *Disassembly, cleaning, reconditioning, reassembly and final check.*

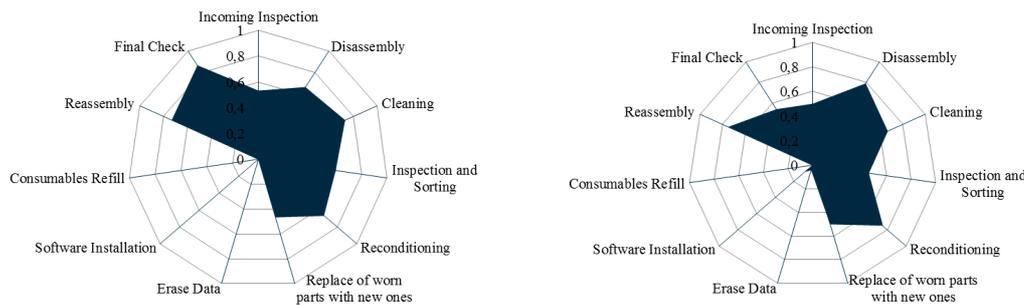


Figure 9: Generic remanufacturing process steps in the heavy duty/off road industry (left chart) and the machinery industry (right chart).

The generic process steps, which are performed in at least 60 per cent of the companies in the heavy duty / off road industry are: *Disassembly, cleaning, inspection and sorting, reconditioning, reassembly* and *final check*.

In the machinery industry, the generic process steps, which are performed by at least 60 per cent of the companies, are: *Disassembly, cleaning, reconditioning and reassembly*. The *final check* is done by 54 per cent of the companies.

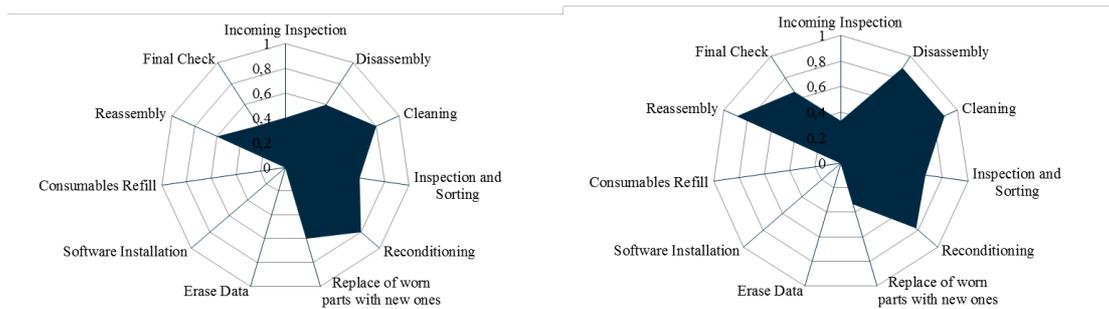


Figure 10: Generic remanufacturing process steps in the marine industry (left chart) and the medical industry (right chart).

In the marine industry, the generic process steps, which are performed by at least 60 per cent of the companies, are: *Disassembly, cleaning, inspection and sorting, reconditioning, replacement of worn parts with new ones* and *reassembly*.

The generic process steps, which are performed in at least 60 per cent of the companies in the medical industry are: *Disassembly, cleaning, inspection and sorting, reconditioning, reassembly* and *final check*.

The result of the rail industry aren't illustrated as only two companies from this industry sector participated in the study. That is not enough to present representative results.

In the figures 11, 12 and 13, the distribution of the generic remanufacturing process steps, depending on the business model, is illustrated.

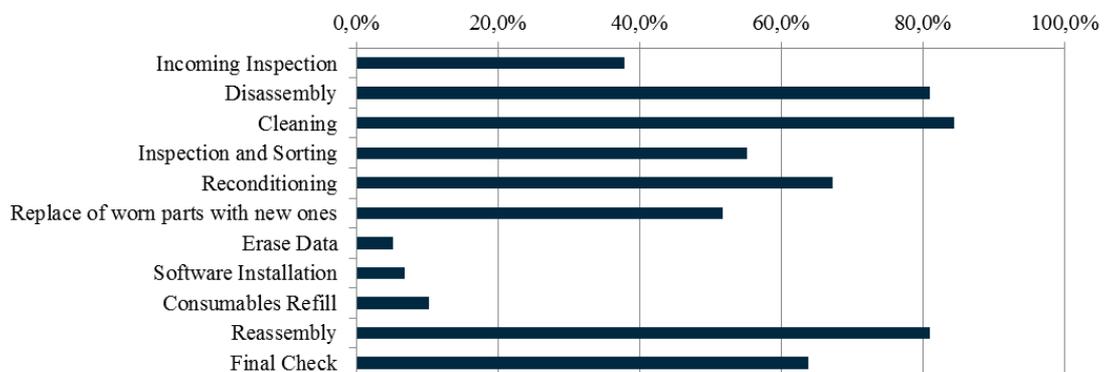


Figure 11: Generic remanufacturing process steps performed within OEMs / OESs.



Figure 12: Generic remanufacturing process steps performed within Third-party / Independent Remanufacturers (IR).

According to figure 11 and 12, there is no big difference between the generic remanufacturing processes performed in OEMs/OESs and Third-party / Independent Remanufacturers (IR), besides the role of technical cleanliness. That seems to play a bigger role for OEMs/OESs than it does for Third-party / Independent Remanufacturers (IR).

In the following, the distribution of the generic remanufacturing process steps are presented in more detail.

Figure 13 illustrates, that the generic remanufacturing process step *incoming inspection* is performed mainly in the aerospace industry sector, followed by the consumer goods industry sector. Furthermore, less than 30 per cent of the companies in the automotive and the furniture industry and none of the companies in the rail industry sector perform *incoming inspections*.

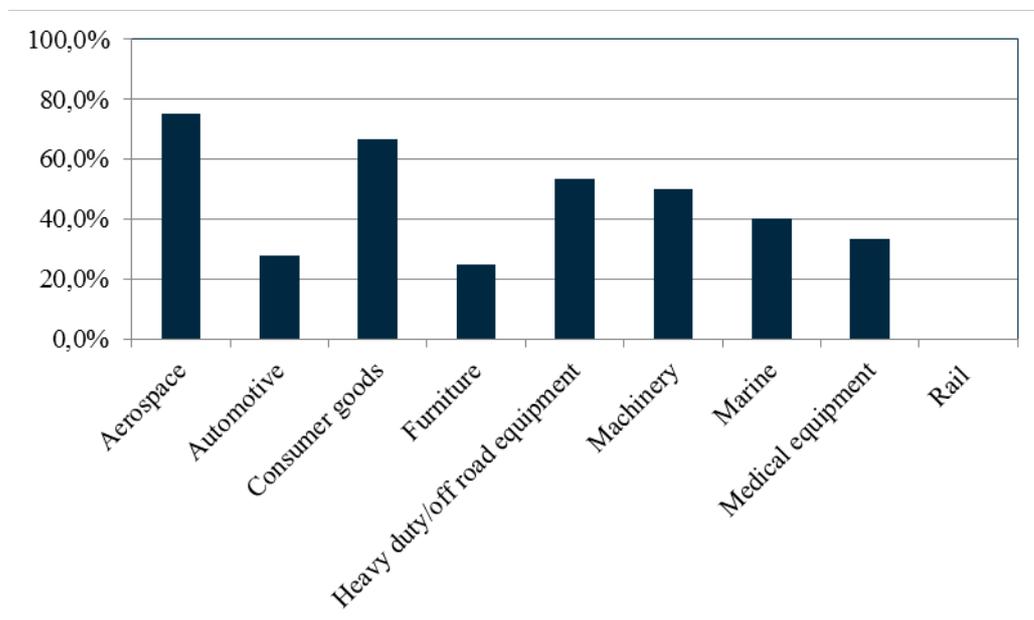


Figure 13: Distribution of the generic remanufacturing process step *incoming inspection*.

In figure 14, it is illustrated, that more than 60 per cent of the companies disassemble their products. It seems, that it is not necessary to disassemble all products in all industry sectors within the remanufacturing process.

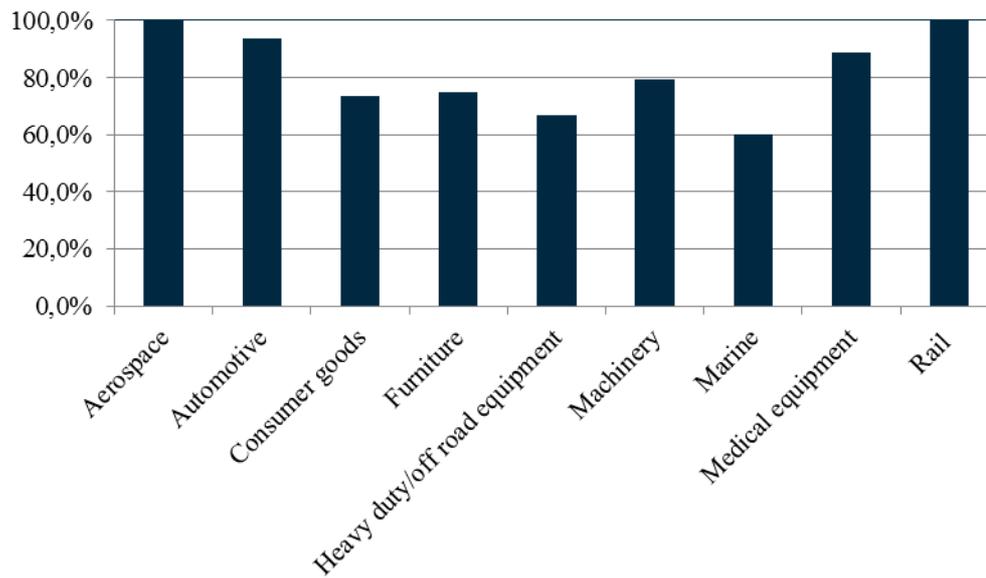


Figure 14: Distribution of the generic remanufacturing process step *disassembly*.

The generic remanufacturing process step *cleaning* is performed at all participating companies in the rail industry sector, probable due to the dirty cores. Furthermore, cleaning is also a big issue in the medical equipment industry sector, probably due to the requirements regarding technical cleanliness in this sector. In the automotive and furniture industry sector only 50 per cent of the companies indicated *cleaning* as one of their generic remanufacturing process steps.

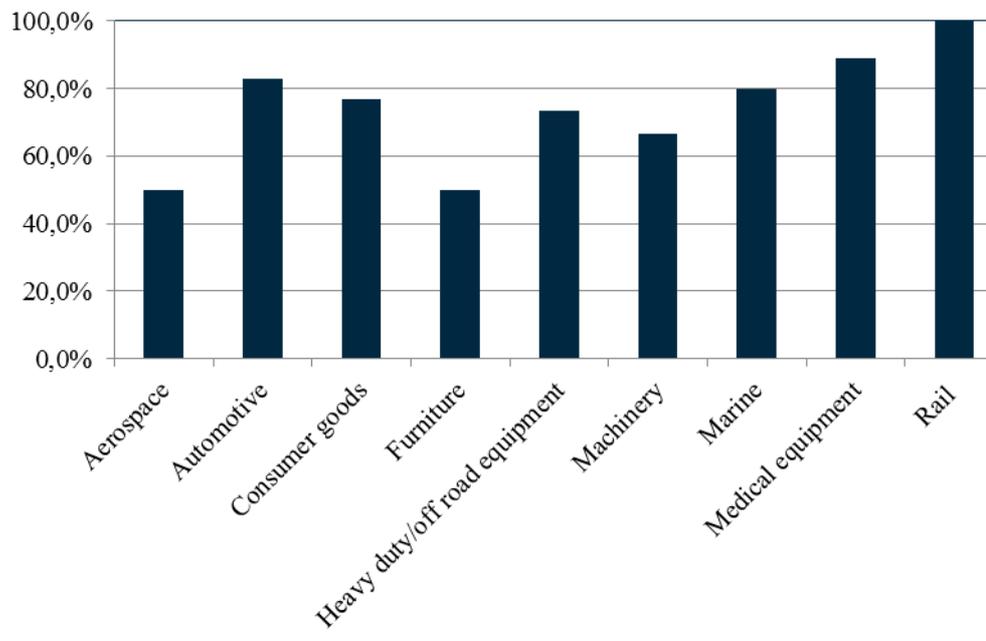


Figure 15: Distribution of the generic remanufacturing process step *cleaning*.

In figure 16, it is illustrated that the generic remanufacturing process step *inspection and sorting* is performed at 100 per cent of the companies in the rail industry sector, but at none of the companies in the furniture industry sector. Also only 20 per cent of the companies in the consumer goods industry sector indicated that process step as a generic remanufacturing process step performed in their companies.

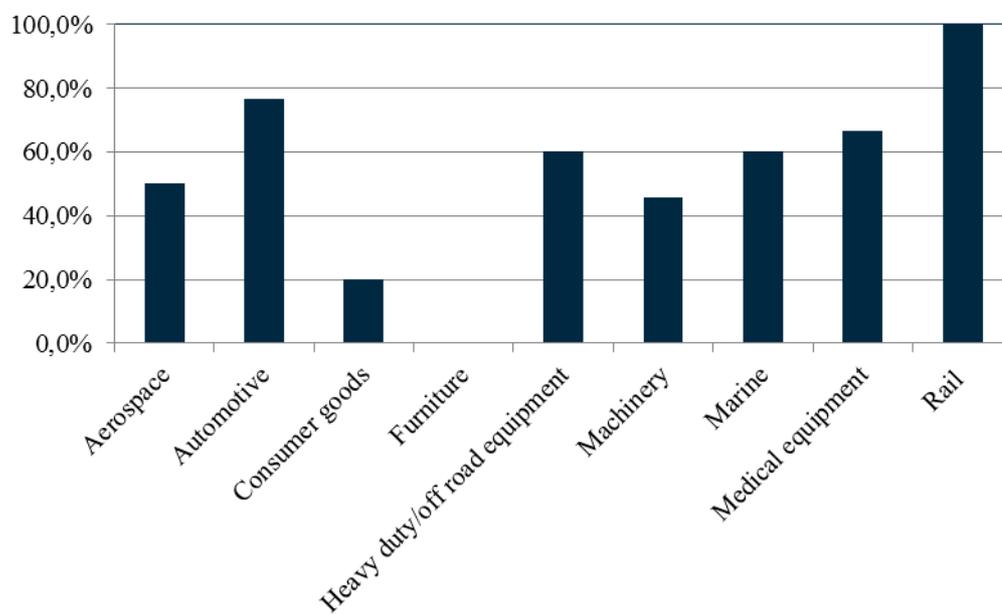


Figure 16: Distribution of the generic remanufacturing process step *inspection and sorting*.

Figure 17 illustrates, that *reconditioning* is performed in all companies in the rail and the aerospace industry sector, but only in less than 50 per cent in companies of the furniture and the consumer goods industry sector. The reason might be, that the remanufacturability of products in the aerospace and the rail industry sector is higher as in the furniture and consumer goods industry sector.

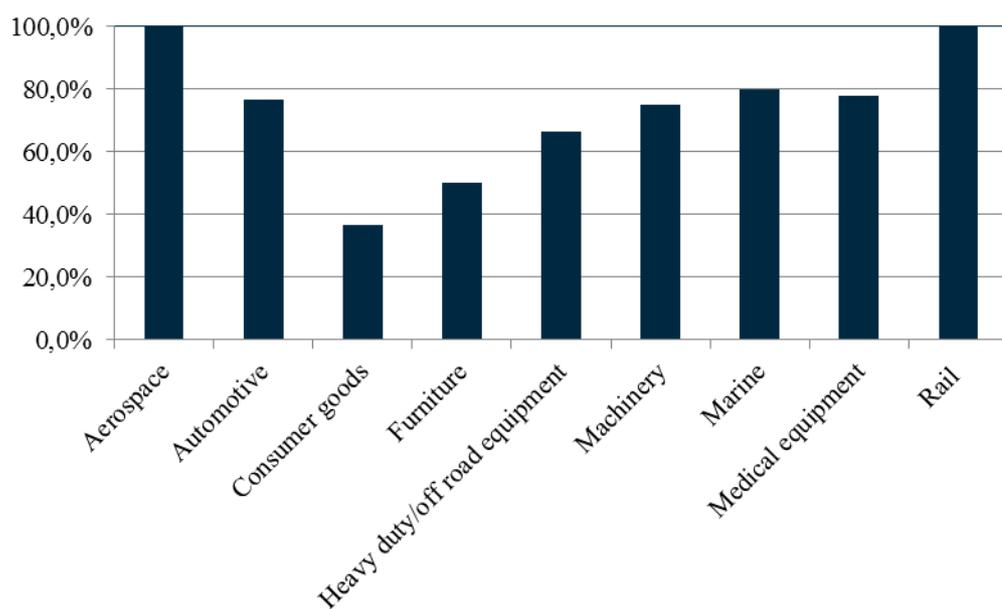


Figure 17: Distribution of the generic remanufacturing process step *reconditioning*.

The *replacement of parts* is mainly indicated as generic remanufacturing process step in the consumer goods industry sector, which is in line with the results shown in figure 17. The relatively high indication within the marine industry sector can be argued with the high wear of the parts in the marine environment.

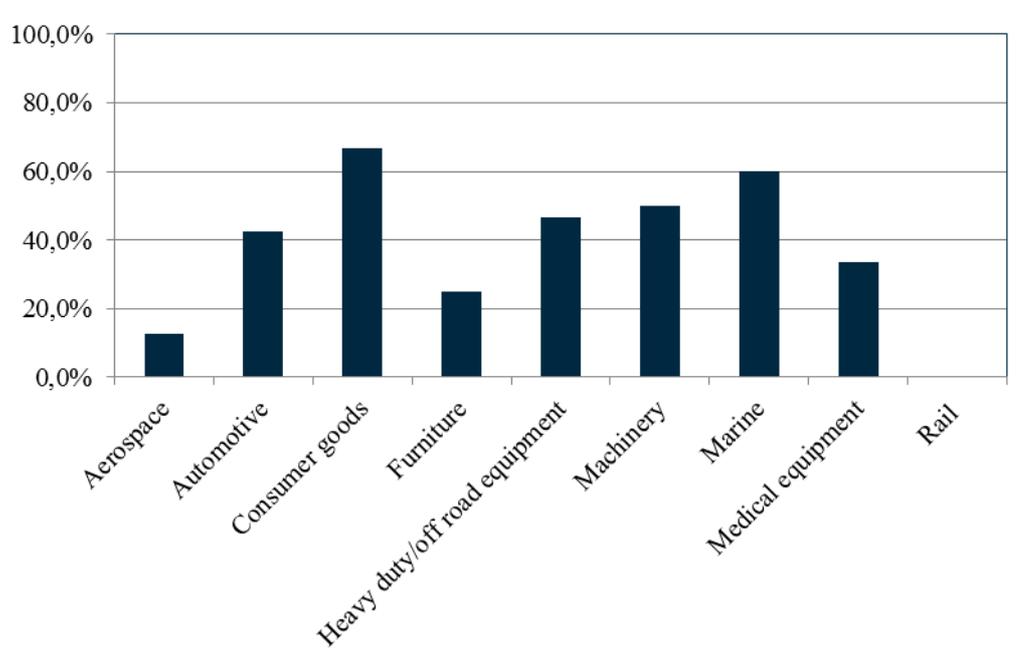


Figure 18: Distribution of the generic remanufacturing process step *replace of worn parts with new ones*.

The generic remanufacturing process step *reassembly* is performed in at least 60 per cent of the companies besides the furniture industry. The reason for that might be, that the products in the furniture industry are assembled at the customers' facilities and not in the facilities of the remanufacturing companies. It also seems, that not only reassembled products are sold but also single parts or components are sold.

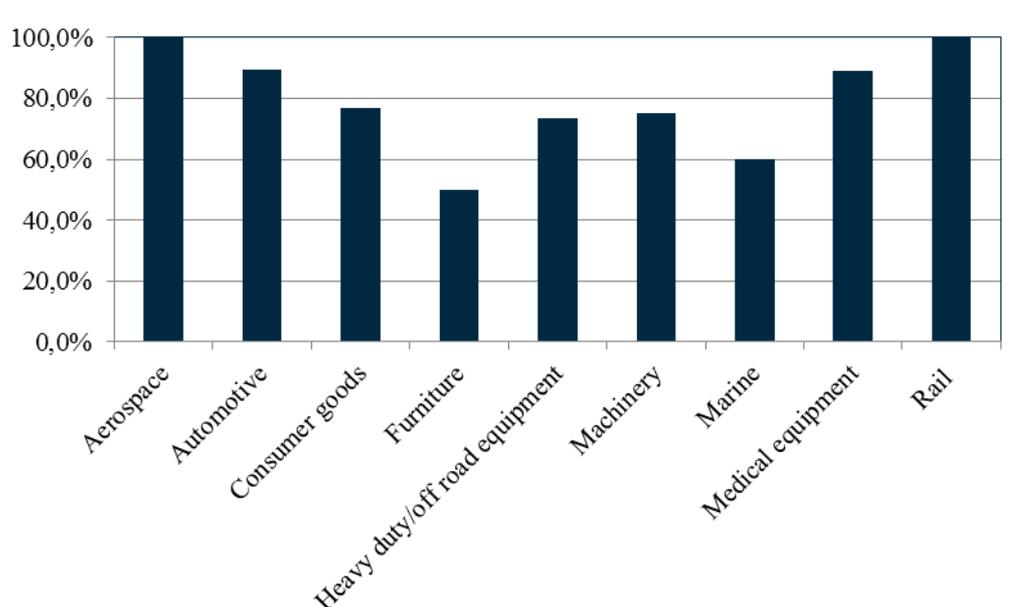


Figure 19: Distribution of the generic remanufacturing process step *reassembly*.

The generic remanufacturing process step *final check* is performed at 100 per cent of the companies within the rail industry sector but only at 40 per cent within the marine industry sector. It might be, that the quality assurance is performed within other generic remanufacturing process steps and thus was not mentioned as a single generic remanufacturing process step.

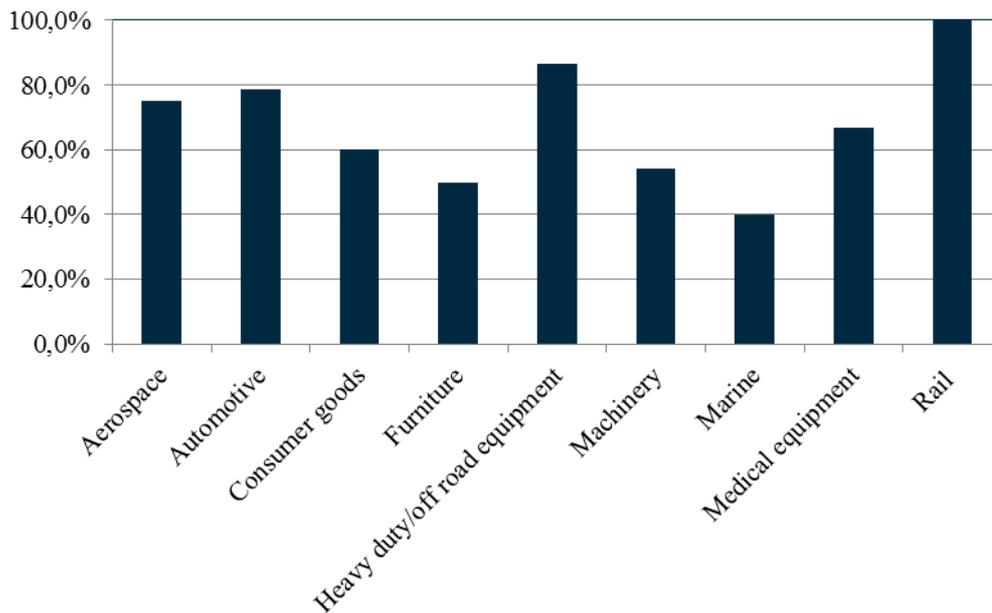


Figure 20: Distribution of the generic remanufacturing process step *final check*.

The generic remanufacturing process step *erase data* is only performed in the consumer goods sector at around 20 per cent of the companies and very little in the machinery and automotive industry sectors. The generic remanufacturing process step *software installation* is performed also in the consumer goods industry sector, the furniture industry sector and the medical equipment at around 20 per cent of the companies each. Furthermore, also very little in the machinery and the automotive industry sector. The *consumables refill* is only indicated as generic remanufacturing process step in the consumer goods industry sector at around 20 per cent of the companies.

Conclusion and Outlook

The aims of the study are to present the industry sector specific remanufacturing processes as well as the similarities and differences of these processes.

Therefore, the data of 105 replied questionnaires, mainly from European remanufacturing companies, were analyzed.

The main results of the study are, that there are differences regarding the generic remanufacturing process steps between the industry sectors. But the generic process steps disassembling, cleaning and reassembly are performed in nearly 80% of the participating companies. The generic process steps disassembly, cleaning, reconditioning, reassembly and final check are performed at 60 per cent of the participating companies, at least.

Furthermore, there is no difference regarding generic remanufacturing process steps performed at OEMs/OESs and Third-party / Independent Remanufacturers.

At the end of the day, the paper supports the remanufacturing industry by creating a better understanding of remanufacturing processes in different industry sectors. The results are the base for workshops with industry representatives to discuss opportunities of cross sectoral learning and exchange of know how.

In future research, we aim to analyze remanufacturing processes in more detail, e.g. production planning and control, disassembly or cleaning. Furthermore, we aim to analyze industry sector specific challenges and potential solutions in more detail. Thus it will be possible to initiate targeted research projects to face today's and tomorrow's challenges in the field of remanufacturing.

Acknowledgement

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References

- [1] IFA Hannover and IPA Stuttgart (2010). *ProdLog-Design – Reifegradbasierte Entwicklungspfade zur leistungssteigernden Gestaltung der Produktionslogistik in kleinen und mittleren Unternehmen*.
- [2] VDI Zentrum Ressourceneffizienz (2014). *Ansätze zur Steigerung der Ressourceneffizienz im Automobilbau*. Available on: http://www.ressource-deutschland.de/fileadmin/user_upload/downloads/kurzanalysen/2014-Kurzanalyse-VDI-ZRE-05-KFZ.pdf.
- [3] European Commission. *Circular Economy Strategy*. Available on: http://ec.europa.eu/environment/circular-economy/index_en.htm
- [4] The Ellen MacArthur Foundation. *Circular Economy System Diagram*. Available on: <http://www.ellenmacartherfoundation.com>.
- [5] Östlin J, Sundin E, Blörkman M. (2008). Business Drivers for Remanufacturing. In: *Proceedings of the 15th CIRP Conference on Life cycle Engineering*, pp. 581-586. Sydney: The University of New South Wales.
- [6] Hauser W, Lund R.T. (2003). *The Remanufacturing Industry: Anatomy of a Giant*. Boston, Massachusetts: Department of Manufacturing Engineering, Boston University.
- [7] Nasr N, Thurston M. (2006). *Remanufacturing: A Key Enabler to Sustainable Product Systems*. In: *Proceedings of the 13th CIRP International Conference on Life Cycle Engineering (LCE)*.
- [8] Östlin J. (2008). *On Remanufacturing Systems: Analyzing and Managing Material Flow and Remanufacturing Processes*. Dissertation. Linköping: Department of Management & Engineering, Linköping University.
- [9] Köhler D. C. F. (2011). *Regenerative Supply Chains. Regenerative Wertschöpfungsketten*. Dissertation. Aachen: Shaker Verlag.
- [10] Kara H. (2010). *Comparative Carbon Footprint Analysis of New and Remanufactured Inkjet Cartridges*. Centre for Remanufacturing and Reuse.
- [11] Sundin E, Lee H M (2012): In what way is remanufacturing good for the environment? In: Matsumoto et al., (Eds.), *Design for Innovative Value Towards a Sustainable Society, Proceedings of the EcoDesign 2011 International Symposium*. Dordrecht: Springer Science + Business Media.
- [12] Steinhilper R. (1999): *Produktrecycling. Vielfachnutzung durch Mehrfachnutzung*. Stuttgart: Fraunhofer IRB.
- [13] Freiburger S. (2007): *Prüf- und Diagnosetechnologien zur Refabrikation von mechatronischen Systemen aus Fahrzeugen*. Dissertation. Aachen: Shaker Verlag.

[14] Parker D. et al (2015): *Remanufacturing Market Study*. ERN - European Remanufacturing Network.