Abstract

Remanufacturing is one of the preferable reuse scenario for worn out or obsolete products. It facilitates multiple usages of the products by providing several life cycles. Remanufacturing has a big potential for cost savings regarding energy and materials usage. It might have also positive social impact. The majority of the companies which are involved in the remanufacturing operations are small and medium sized (SME). Very often operations in these companies are organized by rule-of-thumbs (expert knowledge). In remanufacturing a broad spectrum of boundary conditions has to be considered, in contrast to new production. This situation results mainly from the fact that numerous cores’ models (old parts) have to be reworked in the same workshops/production line. Modern SME lack capacity, know-how and technical infrastructure for adapting abstract complex theoretical models. The aim of this paper is to discuss the method, which provides cross company valid sustainability assessment criteria. The method is elaborated based on the literature review and case studies. Authors present the application potential of the method in remanufacturing companies.

Keywords: remanufacturing; sustainability assessment; maturity

1. Introduction

Sustainability is defined as „development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. On a company level the requirements of this policy can be translated as:

- Economical utilization of the resources,
- Environmental friendly utilization of the resources,
- Utilization of the resources in the way, that provide ergonomics and safety at the facility and minimum external burden to affect the surrounding communities.

Increasing importance of the sustainability has created a new framework for companies existence and turned out to be a key factor of success in competition. The implementation of a sustainability strategy might drive innovation and provide better cost effectiveness. Particularly with respect to environmental and social aspects, it is important to keep track with the economic development. Beside conformity with minimum requirements like quality management (ISO 9001) and environmental management (ISO 14001), there is a growing importance of health and safety aspects (BS OHSAS 18001) as well as energy management requirements (ISO 50001) for the acceptance of orders, especially in the automotive supplier industry [2, 3]. There are methods for assessing and controlling sustainability in the industry (called Corporate Sustainability) but very often they are not applicable for small and medium sized companies.
Companies in the remanufacturing sector face problems when it comes to integrating economic, ecological and social aspects in their daily business. Furthermore, the existing theoretical approaches leave SME alone with sustainability matters as well as energy and resource savings because they only focus on implementing measurement systems [4]. SME have lack capacity, know-how and technical infrastructure for adapting complex theoretical models. There is a need for simple procedure which guides SME on how to identify optimization potentials in their remanufacturing processes, then derive and implement improvements based on sustainability indicators.

The aim of this research is to provide SME with easy applicable decision support method for analysis and implementation of appropriate measures for increasing sustainability of the remanufacturing process. The aim of this paper is to discuss the method, which provides cross company valid sustainability assessment criteria. The method is elaborated based on the literature review and case studies. Authors present the application potential of the method in remanufacturing companies.

2. Remanufacturing process and sustainability

2.1. Remanufacturing and sustainability

Remanufacturing is defined as industrial process in which returned products named as cores are restored to their full functionality in order to be used for at least another lifecycle. The generic structure of the remanufacturing process is defined by the following phases [5, 6]:

- inspection,
- cleaning,
- disassembly,
- reprocess,
- reassembly,
- testing.

Figure 1 presents the example of the remanufacturing process logic.

![Figure 1. The example of the remanufacturing process](image)

Remanufacturing contributes considerably to global sustainability, as they pave the way for closed loop life cycles [8]. In remanufacturing, typical process steps of new parts production are expanded by the recovery operations (e.g. disassembly, cleaning, reprocessing, etc.). For its variety of process patterns, the remanufacturing industry is particularly predestined for research on sustainability aspects. Remanufacturing of automotive parts, promises enormous economic, ecological and social potential [9].

Remanufacturing provides the multiple reuse of materials, so it can be seen as an environmentally friendly way of salvaging the resources. Moreover due to recovery of worn out or obsolete products it has also positive social impact. For example remanufactured products can be distributed to the low-income markets, where customers cannot afford to buy new products but require the functionality of these products in order to improve their quality of the life.

2.2. Sustainability assessment

There is a number of research which assess economic and environmental [e.g.10] or social aspects of remanufacturing. Most of them focus on LCA (life cycle assessment) of the remanufactured products in comparison to the new products or recycled products. For example Shau et al. [11] proposed use LCA for suitability assessment and provided analyses of three different design alternatives for remanufactured alternators. In that paper researchers concluded that by applying LCA, LCC (life cycle costing) they are been able to quantify some indicators for the life cycle sustainability of the three different remanufactured alternators and remanufacturing localization options. In practice LCA or LCC analyses require a big scope of data which usually is not available for SMEs. Sundin and Lee [12] provided a comparison of studies which were focused on the assessment of the environmental performance of remanufacturing. They identified a number of case studies from remanufacturing companies and discussed the environmental indicators which were analyzed in those research papers. They classified the environmental measures used for assessment of the remanufacturing process, as following [11]:

- Direct: consumption of materials, energy and waste generated, which translates this directly to resource savings,
- Indirect: Life Cycle Assessment methods, which calculates eco-points to assess the environmental impact, they assess the long-term potential environmental impact.

Both direct and indirect measures require a rather big scope of data which is very often not available for SMEs.

Even more difficult is to apply the social performance indicators (see e.g. [13]).

After literature review and case studies in remanufacturing companies a need for elaboration of qualitative assessment method has been identified. The elaborated by the authors so called qualitative method for
sustainability maturity in remanufacturing companies is presented in the next Section.

3. Maturity level assessment

3.1. Method description

The maturity levels are defined based on the guidelines from ISO/IEC 15504 Process Assessment, which provides the reference model for the maturity models [14]. Each stage of the remanufacturing process maturity is consisting of capability levels which in turn consist of the process attributes and further consist of generic practices.

In figure 2 is presented the maturity level concept. The company can achieve level from “0” (process not existing) to maximum “4” which is optimal from sustainability assessment perspective. For detailed assessment in our maturity models are taken in consideration only existing process (from level “1” to level “4”).

The method consists of questionnaire which allow the companies to perform self-assessment of their sustainability level. The purpose of this self-assessment is to identify the potential for optimization of resources utilization in the remanufacturing companies. The questionnaire is divided into three dimensions of sustainability:

- economic performance,
- ecological performance, and
- social performance.

The results of this self-assessment will allow to name the maturity level at each company. The remanufacturing company by giving yes/no answers can classify the maturity level in each category. Each of the dimensions consists of five categories which are then described by 4 detailed questions referring to particular maturity level. Figure 3 presents the categories which are assessed from minimum “1” to maximum “4”.

The maturity level in each category is a result of numbers of the “yes” answers company has indicated in each category. In figure 3 is presented the example of the detailed questions for the dimension “ecological performance” in each of the five categories which were defined before. “Yes” answer is insert as “1” and “no” answer is indicated as “0”. The logic of the questions is following the requirements of the maturity model.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Category</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Ecological</td>
<td>Energy Efficiency</td>
<td>1-4</td>
</tr>
<tr>
<td>Performance</td>
<td>Material Efficiency</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Disposal and Recycling</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Compressed Air</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Emissions</td>
<td>1-4</td>
</tr>
<tr>
<td>II. Economical</td>
<td>Inventory</td>
<td>1-4</td>
</tr>
<tr>
<td>Performance</td>
<td>Scrap and Rework</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Production Organisation</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Production Disruptions</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Quality Management</td>
<td>1-4</td>
</tr>
<tr>
<td>III. Social</td>
<td>Workplace Design</td>
<td>1-4</td>
</tr>
<tr>
<td>Performance</td>
<td>Ergonomics and Safety</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Training and Development of Employees</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Innovation Management</td>
<td>1-4</td>
</tr>
<tr>
<td></td>
<td>Corporate Image</td>
<td>1-4</td>
</tr>
</tbody>
</table>

For example in Figure 4 for category “energy efficiency” maturity level is “2” what means that a company implements some optimization methods but the systematic approach is missing. The method is based on assumption that the maturity levels are consequent, so e.g. level 3 cannot be achieved without meeting requirements of the level 2. The questions were constructed based on the results of the literature review and authors previous research [15]. The conditions of remanufacturing operations which were identified in the previous stage of SIRO (Sustainability in Remanufacturing Operations) were taken in consideration.

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Question 1: Are energy costs significant in your company?

Y/N

Question 2: Is there an overview of the distribution of energy consumptions of existing equipment (e.g. machine, lighting)?

Y

Question 3: Do you implement measures to lower energy consumption?

N

Question 4: Does an energy management system exist (e.g. ISO 50.001)?

N

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Question 1: Do you lose production materials in your company due to defective goods and offcuts?

Y

Question 2: Is the material input and material output for each stage of production/remanufacturing process known and quantifiable?

Y

Question 3: Does your company apply any procedures to reduce materials / parts usage?

N

Question 4: Do you have a standardized procedure in your company, which supports the minimal and environmentally friendly usage of resources?

N

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Section 3: Disposal and Recycling
Question 1: Do you create production and packaging waste in your company (surplus material, packaging, waste water)? Y
Question 2: Does your company monitor the amount of production and packaging waste? Y
Question 3: Does your company apply procedures/methods to reduce the amount of waste? Y
Question 4: Do you have procedures/systems which separates waste according to recycling strategies? Y

Section 4. Compressed Air

Question 1: Does your company use compressed air in the production process? Y
Question 2: Is the amount of compressed air consumption, the net infrastructure and the compressor technology known? Y
Question 3: Are vulnerabilities and leaks detected and immediately fixed? Y
Question 4: Does a periodic review of the compressed air network take place for vulnerabilities and leaks (including a review of compressed technology)? N

Section 5. Emissions (including CO2 and waste water)

Question 1: Is your company able to identify emissions and potential toxic substances in production/remanufacturing processes? Y
Question 2: Does your company monitor and document places in production/remanufacturing where emissions/toxic substances are created? Y
Question 3: Is there a standardized system/procedure to reduce these emissions and substances? N
Question 4: Are additional actions (beyond fulfillment of law regulations) performed in order to reduce the emissions level? N

Fig. 4. Example of the maturity assessment questions in the dimension “ecological performance”.

3.2. Method testing

The method was tested by comparison of group of five European and five American companies. The European companies where selected based on the previous authors experience working with Polish and German companies. The group of US companies was selected from remanufacturers, participating in the BIG R Show organized by the Automotive Parts Remanufacturers Association (Las Vegas in November 2013. The simplified characteristic of the companies which took part in method testing were as shown in Table 1. Due to the confidentiality issues the names of the companies are not revealed.

Table 1. Pilot group of companies for method testing

<table>
<thead>
<tr>
<th>Company</th>
<th>Products</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Brake systems</td>
<td>USA</td>
</tr>
<tr>
<td>A2</td>
<td>Automotive electronic, mechatronic, hydraulic and mechanical parts</td>
<td>USA</td>
</tr>
<tr>
<td>A3</td>
<td>Automotive electronics</td>
<td>USA</td>
</tr>
<tr>
<td>A4</td>
<td>Brake systems, steering systems</td>
<td>USA</td>
</tr>
<tr>
<td>A5</td>
<td>Alternators, starters, generators</td>
<td>USA</td>
</tr>
<tr>
<td>E1</td>
<td>Transmissions, engines</td>
<td>Germany</td>
</tr>
<tr>
<td>E2</td>
<td>Turbochargers</td>
<td>Germany</td>
</tr>
<tr>
<td>E3</td>
<td>Diesel fuel injection pumps</td>
<td>Germany</td>
</tr>
<tr>
<td>E4</td>
<td>Starters, alternators</td>
<td>Germany</td>
</tr>
<tr>
<td>E5</td>
<td>Starters, alternators</td>
<td>Poland</td>
</tr>
</tbody>
</table>

The Authors have chosen pairwise comparison of American and European companies due to the fact that that US remanufacturing industry is reported as more mature as European. Also, some earlier investigations of the European and United States remanufacturing industries where taken in consideration by the design of method testing protocol (see e.g. Lund [16] and Sundin et al. [17]).

In figure 5 are presented the results of the group of the American companies.

Fig. 5. Maturity assessment – pilot study among American companies.

The results allows to identified the areas with biggest potential for improvements. For example in case of analyzed American companies are visible areas for implementation of improvement measures:

- Energy efficiency,
- Ergonomics and work safety,
- Emissions (including waste water and CO2),
- Compressed air.

In figure 6 are presented the results for the group of European companies.

Fig. 6. Maturity assessment – pilot study among European companies.

The Authors have chosen pairwise comparison of American and European companies due to the fact that that US remanufacturing industry is reported as more mature as
In the case of European companies the following areas for implementation of improvement measures:

- Productions disruptions,
- Energy efficiency,
- Ergonomics and safety,
- Corporate image.

Figure 7 presents the pairwise comparison of the average results for US and EU companies.

4. Conclusions and further research

The paper presents easy applicable decision support method for analysis and implementation of appropriate measures for increasing sustainability of the remanufacturing process. Authors present method, which provides cross company valid sustainability assessment criteria.

The group of companies for method test was limited but some different perception of American companies and European can be already perceived. Due to the longer existence of the remanufacturing sector in USA and Europe the US companies indicated higher values during self-assessment in the areas related to the materials efficiency and disposal a assessment in the areas related to the materials efficiency.

The further research will include the creation of the online tool which allow the companies to make the self-assessment including the recommendation of suitable and effective optimization methods.

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