



THE LEAN APPROACH FOR IMPROVEMENT OF THE SUSTAINABILITY OF A REMANUFACTURING PROCESS

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ABSTRACT. Background: The lean production is a well-established managerial concept, which helps companies to provide the customer value and to reduce cost. Recently it gains a lot of attention among the remanufacturers. In this paper the assumption is made that remanufacturing process is more sustainable, if there will be efficient utilization of the resources. The resource utilization is efficient when there is no waste of resources. The implementation of lean principles and tools into a remanufacturing process can benefit to improved sustainability but also it suffers some constrains, which are identified in this paper.

Methods: The research methodology consists of a literature review, where research papers from the Scopus, Science Direct and Business Source Premier databases were used. The search criterion was the phrase "lean remanufacturing". On the basis of literature review the lean remanufacturing problems are identified. The framework for lean remanufacturing analysis was established. Author presents also case studies on assessment of the leanness of remanufacturing process and discusses the potential for waste elimination in order to improve sustainability of remanufacturing process.

Results: Problem identification and analysis framework of lean remanufacturing process is discussed. The case studies results are analysed in the context of the finding of the literature review. The advantages and constrains of lean remanufacturing are discussed.

Conclusions: A remanufacturing process is more complex than the respective production process. The implementation of lean production principles and tools into remanufacturing process is at a very early stage comparing to the traditional manufacturing. There are evidences from the industrial studies and the academic research on lean remanufacturing benefits. There is a need to distinguish between lean remanufacturing on an operational and a strategic level. From the perspective of sustainability of remanufacturing process an operational framework seems to be more suitable.

Key words: lean production, remanufacturing process, waste reduction, sustainability.

INTRODUCTION

Remanufacturing is an example of sustainable practice in a business environment. It allows multiple usages of the same product. It has a positive environmental impact because usually in the remanufacturing processed reused components and recycled materials are applied. Remanufacturing process requires less energy than the primary production of the same goods. Furthermore it has positive economic impact, because costs of remanufacturing are lower than the primary

production of the similar products. The positive social impact is achieved for example by the redistribution of remanufactured products to the lower income countries where first life cycle products won't be availed for big number of customers due to the too high price. The remanufacturing facilities create more working places than respective production facilities because it is difficult to automate most of the remanufacturing operations.

Remanufacturing companies especially small and medium sized face problems to achieve adequate economy of scale of their

operations and an operational excellence. The assumption is made that remanufacturing process is more sustainable, if there will be efficient utilization of the resources. The resource utilization is efficient when there is no waste of resources. For these reasons there is a growing interest in the application of the lean principles in remanufacturing facilities.

This paper presents the overview of the literature analysis on the challenges and opportunities to be lean in a remanufacturing facility. The tool for quick scan of the remanufacturing facility is discussed as well as some case studies results. At the end of this paper are stated conclusions and are described further research steps.

THEORETICAL BACKGROUND - REMANUFACTURING PROCESS AND THE LEAN PRODUCTION PRINCIPLES

Remanufacturing is an industrial process, which allows to bring back the obsolete or worn out products to "like a new" condition. The remanufacturing process consists of operations which might be put in different order or omitted. For this reason operations were defined in a generic way by Sundin and Bras [2005]. In the literature different classification of remanufacturing operations can be found (see table 1). The sequence and amount of the above mentioned activities is case-dependent.

Table 1. Remanufacturing operations/phases
Tabela 1. Operacje/fazy w procesie remanufacturing

Author	Remanufacturing phases/operation	Sequence predefined
[Steinhilper 1998]	disassembly, cleaning, inspection, reconditioning, reassembly and testing	yes
[Bras & Hammond 1996]	cleaning, damage correction (repair, refurbishment, replacement), quality assurance (inspection and testing) and part interfacing (disassembly and reassembly).	no
[Sundin 2004]	inspection, cleaning, disassembly, storage, reprocessing, reassembly, testing	no
[Ostlin 2006]	pre-disassembly, disassembly, reprocessing, reassembly and post-reassembly	yes
[Kim et al. 2008]	disassembly, cleaning, inspection & storing, reconditioning & replenishment, reassembly, final testing & packing	yes
[Golinska 2013]	collection & material handling, disassembly, cleaning & inspection, parts reprocessing/re-supply, reassembly, testing, painting and packing	no

Source: own elaboration

In this paper for further reference the considered remanufacturing phases are:

- preassembly,
- disassembly, cleaning & sorting,
- reprocessing & replacing,
- reassembly,
- post-reassembly (testing& packing).

Sudin [2006] also stated that "remanufacturing is often a more complex process than manufacturing, due to a higher level of uncertainty in process steps and time, as well as unpredictability of cores' (returned products or their parts) quality and quantity". The papers on possibilities of the implementation of lean principles into

remanufacturing started to appear about 15 years ago. One of the first works on this topic by Amezcua and Bras [1996] reported on the successful lean remanufacturing of the clutch. The reported by the authors benefit was a more robust process with lower costs than by the remanufacturing process that utilized craft and mass production practices. The analysed company had rather high output of remanufacturing (423 pcs/day) and applied batch production. They defined lean production as an entire production system with the fundamental characteristics [Amezcua and Bras, 1996] as following:

1. economies of scale (from mass production),
2. production of large varieties of products (from craft production),

3. elimination of non-value added resources and activities, and
4. integration of all production system elements and functions (functional relationships).

The economy of scale is usually obtained by standardization. In the remanufacturing facilities, where proliferation of products is very high, it is rather difficult to introduce the standardization. Furthermore the quality and characteristics of products cause a situation when the amount of work and the routings of reprocessed units are stochastic. Usually when defining the problems of application of lean principles into remanufacturing process seven characteristics are listed as defined by Guide (2000):

- the uncertain timing and quantity of returns,
- the need to balance returns with demands,
- the disassembly of returned products,
- the uncertainty in materials recovered from return items,
- the requirements for a reverse logistics network,
- the complication of material matching restrictions,
- the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.

Petersen [2007] stated that there is no consensus on a definition of lean production among the experts and that the absence of it has a number of consequences for practitioners seeking to implement lean as well as researchers trying to capture the essence of this concept. He identified over 30 lean production characteristics which were addressed by the most cited authors in this field (based on results from Scopus and ISI). The conclusion was made that only continuous improvement and set-up reduction were discussed by all the analysed authors. Petersen [2009] combined the previously identified specific characteristics into the nine collective categories, as listed below:

- Just in time practices,
- Resource reduction,
- Human relations management,
- Improvement strategies,
- Defects control,
- Supply chain management,

- Standardization,
- Scientific management,
- Bundled techniques (e.g. statistical quality control, TPM),

There is on-going academic discussion whether lean is "a collection of waste reduction tools" or more than a set of tools (see e.g. Bicheno, 2004). Hines et al. [2004] distinguished between strategic and operational dimensions of lean. The strategic orientation refers to the customer-centred thinking on the strategic value chain (value creation and understanding customers' requirements). The lean thinking strategic level is based on 5 lean principles: identification of customer value, the management of the value stream, developing the capability to flow production, the use of "pull" mechanisms to support flow of materials, and the pursuit of perfection through reducing to zero waste in the production system [Womack and Jones, 1996]. The operational orientation should focus on application of the shop-floor tools to reduce waste in order to improve quality, cost and delivery (QCD) [Hines et al. 2004].

According to Shah and Ward [2007] lean can be both a general philosophy (lean thinking), as well as has a strong practical orientation (lean toolbox). Petersen concludes that "lean seems to be a reasonably consistent concept comprising just in time practices, resource reduction, improvement strategies, defects control, standardization and scientific management techniques". It can be assumed that lean remanufacturing have the same focus as lean production (see figure 1).

	Strategic	Operational
General philosophy	Lean thinking	Leanness
Practical	Becoming lean	Toolbox

Source: modified from Petersen, 2009

Fig. 1. Approaches to lean production
 Rys. 1. Podejścia do lean production

From the perspective of improving sustainability is it crucial to focus on operational issues of lean implementation. The operational approach presents "shop-floor-

focus" on waste and cost reduction. This can be translated into better utilization of resources in environmental friendly way. Furthermore lean focus on human relations management and improvement provides a base for archiving the social dimension of sustainability.

ASSESSMENT OF A REMANUFACTURING PROCESS LEANNES

The main constrains of remanufacturing in the context of lean production were analysed in some previous research [Kurilova-Palisaitiene and Sundin 2013; Amezquita and Bras 1996; Sundin 2006; Fargher2007, Hunter and Black 2007, Ostlin and Ekholm 2007; Rubio and Corominas 2008]. Based on the findings of these studies the main constraints of remanufacturing can be summarized, as:

- insufficient availability of the good quality cores (lack of just in time supplies),
- high product variability (product proliferation),
- process complexity (stochastic lead times and stochastic routings, variable number of operations needed),
- process bottlenecks (long processing an waiting times),
- product design-related problems (variation of the rate of materials recovered, materials matching problems),
- limited information flow (mainly on incoming cores).

Kurilova-Palisaitiene and Sundin [2013] provided the analysis of the gap between manufacturing and remanufacturing with regards to the 19 characteristics which are important for application of the lean principles. They stated that remanufacturers are much behind manufacturers (17 out of 19 characteristics) but lean principles and tools can help remanufacturers gain competitive advantage. The examples of the successful implementation of the lean tools in remanufacturing at the operational level can be found in the studies of: [Fargher2007, Hunter and Black 2007, Ostlin and Ekholm 2007; Rubio and Corominas 2008; Kunikula and Koch 2011].

In this paper are presented the case studies, which were performed in order to assess the leanness of remanufacturers. The next step includes identification of the improvement potential for sustainability with application of lean tools. The analysed case studies were conducted in 2 steps:

1. Leanness assessment.
2. Toolbox application (value stream mapping, process mapping, waste identification/reduction).

In order to assess the leanness of the remanufacturing facilities the Rapid Plant Assessment (RPA) is applied. This method has been elaborated by Goodson [2002], as a tool for assessment of the leanness of a plant. The RPA method consists of the 2 tools:

- The leanness score matrix for 11 categories - each company is scored from "poor" to "best in class" for each category. The scale for scoring includes options: "poor" equals 1 point, "below average" equals 3 points, "average" scores 5 points, "above average" gets 7 points, "excellent" equals 9 points, and finally "best in the class" is 11 points.
- The leanness questionnaire provides 20 yes/no questions to determine if the plant uses best practises.

The categories of the RPA matrix are presented in table 2. They are assigned to the three dimensions of the sustainability: economic (ECON), ecological (ECO) and social (SOC).

Figure 2 presents example of the leanness levels in the remanufacturing facilities. The companies A,B,C were examined within the SIRO project (Sustainability of Remanufacturing Operations) and the company D is a benchmark from Sundin studies [2004]. All the analysed companies are involved in remanufacturing of the automotive parts (see table 3). They represent all the identified in the literature four types of the remanufacturers: IR- independent remanufacturer, CR- contracted remanufacturer, OEM- original equipment manufacturer, who performs as well remanufacturing of own products, RSP- remanufacturing services provider.

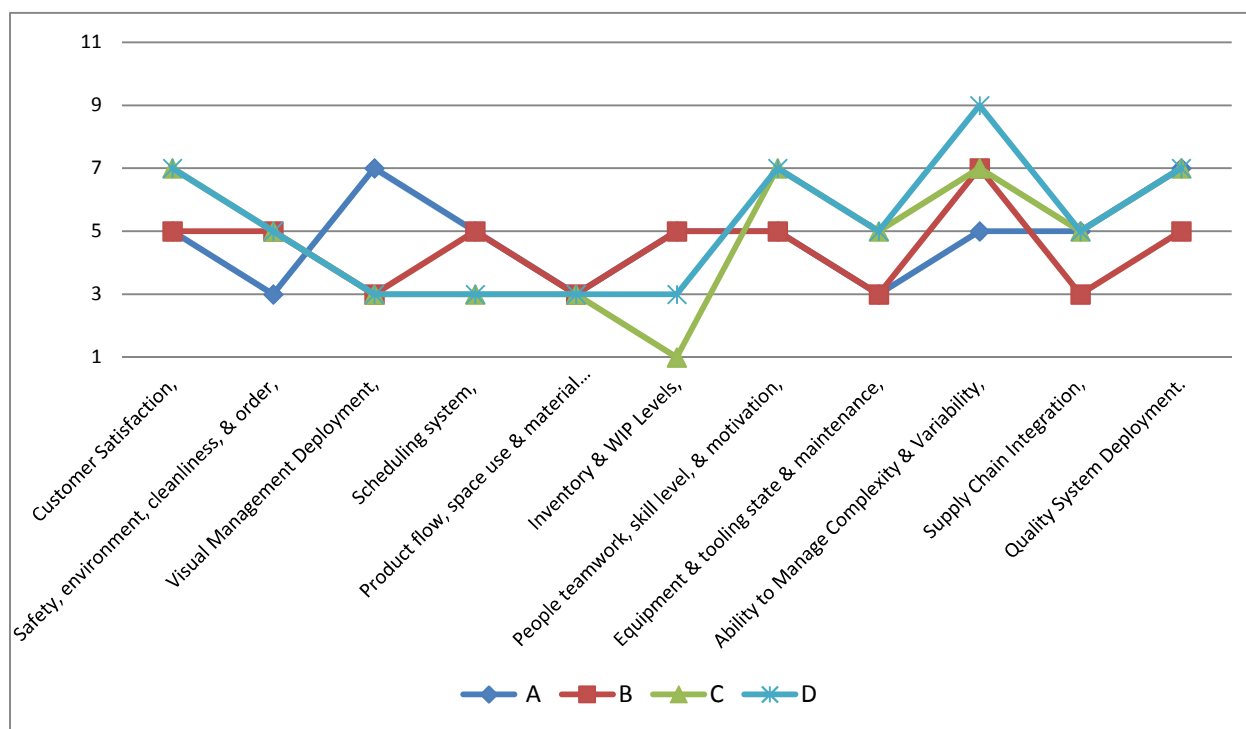
Table2. Categories of the RPA assessment
 Tabela 2. Kategorie w ocenie RPA

Dimension	No	Category
CON/SOC	C1	Customer Satisfaction
SOC	C2	Safety, environment, cleanliness, & order
SOC/ECON	C3	Visual Management Deployment
ECON	C4	Scheduling system
ECON/SOC	C5	Product flow, space use & material movement means
ECON	C6	Inventory & WIP Levels
SOC/EKON	C7	People teamwork, skill level, & motivation
ECON/ECO	C8	Equipment & tooling state & maintenance
ECON	C9	Ability to Manage Complexity & Variability
ECO/ECON	C10	Supply Chain Integration
ECON/SOC	C11	Quality System Deployment

Table3. Categories of the RPA assessment
 Tabela 3. Kategorie w ocenie RPA

	Company A	Company B	Company C	Company D
Remanufactured products	Alternators, starters	Engines	Alternators, starters	Engines
Size	Small	Small	Small	Big
Type	Contracted remanufacturer	Remanufacturing service providers	Independent remanufacturer	OEM

Source: own elaboration



Source: own elaboration

Fig. 3. Facility leanness assessment
 Rys. 3. Ocena Facility Leanness

The assessment on the leanness score matrix allows to identify the categories (C1-C11) of strength and weakness. Categories with low ratings are having the potential for

improvement, and should be explored first to provide the leanness [Godsoon 2002]. The low score of RPA shows the weaknesses of remanufacturing facility. As presented in

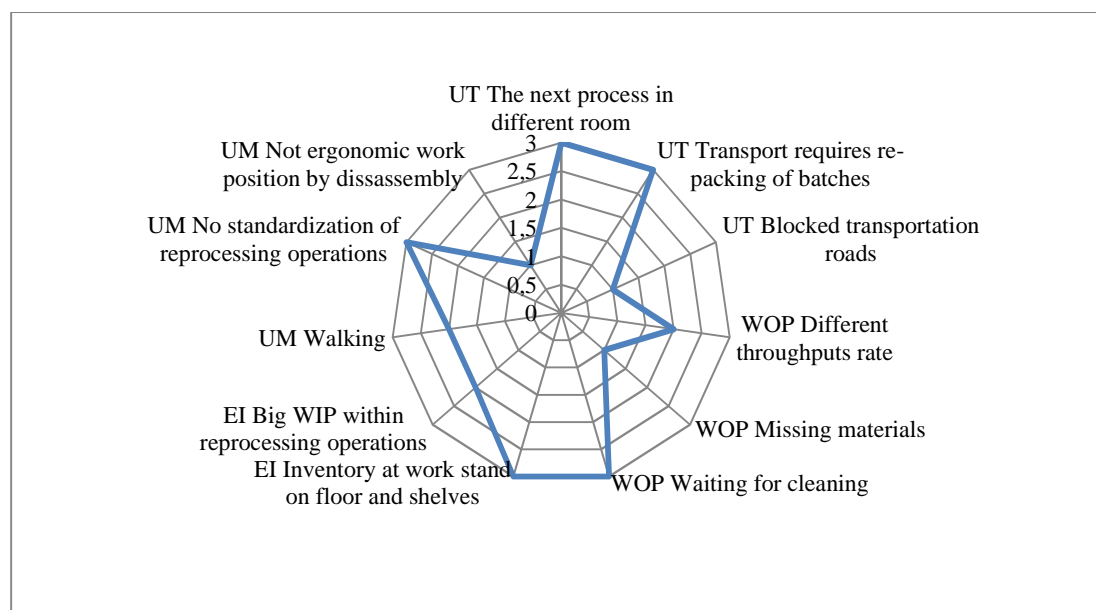
figure 2 companies have low scores mainly in the area related to safety, environment, cleanness & order (social and environmental

dimension) and in the categories related to materials management (C4-C6).

Table 4. Classification leanness results (RPA) into muda type
 Tabela 4. Przyporządkowanie wyników analizy szczupłości (RPA) do typów marnotrawstwa

	RPA Question	RPA Category	Muda type
C1	Q1,2, 20	Customer Satisfaction	Defects/ Underutilization of Employees
C2	Q3-5, 20	Safety, environment, cleanliness & order	Unnecessary Motion/Transport
C3	Q2,4, Q6-10, 20	Visual Management Deployment	Unnecessary Motion /Inappropriate processing/ Overproduction/ Excess inventory/ Underutilization of Employees
C4	Q11, 20	Scheduling system	Excess inventory
C5	Q7,12,13,20	Product flow, space use & material movement	Excess inventory/ Transport/Waiting
C6	Q7,11,20	Inventory & WIP Levels	Excess Inventory
C7	Q6,9,14,15,20	People teamwork, skill level, & motivation	Overproduction/Underutilization of Employees
C8	Q16,20	Equipment & tooling state & maintenance	Inappropriate processing
C9	Q8,17,20	Ability to Manage Complexity & Variability	Overproduction/ Defects
C10	Q18,20	Supply Chain Integration	Defects
C11	Q15,17, 19,20	Quality System Deployment	Underutilization of Employees/ Overproduction/ defects

Source: Golinska 2013



Source: own elaboration

Fig. 4. Example of the muda assessment
 Rys. 4. Przykładowa ocena rodzajów marnotrawstwa

These leanness scores are consistent with the previous literature findings (see previous section). Due to the fact that most of the C1-C11 categories are related to more than one dimension of the sustainability (e.g. ECON/SOC) the analysis is followed by the remanufacturing process analyses with usage of lean toolbox. The results from the leanness matrix and the leanness questionnaire (Y/N) are then translated into

muda questions. The waste identification questions are divided first into 8 muda (waste) types: overproduction (OP), inappropriate processing (IP), waiting for operations (WOP), unnecessary transportation (UT), unnecessary motion (UM), excess inventory (EI), defects products (DP), Underutilization of Employees (UE). Then the muda questions are assigned to the three dimensions of the sustainability. Only questions are picked up which cover area

with low RPA score and "no" answer in the leanness questionnaire. In order to do that a correlation matrix was designed by the author. The matrix was sent to about 30 experts from Academia and industry, which have some experience in lean management. The response rate was about 50% (15 questionnaires received back). Table 4 presents the results of the survey. The matrix correlates leanness categories (C1-C11) and RPA questions (Q1-Q20) to the 8 muda (waste types). The RPA (leanness questionnaire) consists originally of 20 questions, but according to Godson [2002] applies to the all eleven categories so it could be excluded from further analyses. Experts were confident about classification of most questions but questions number 5 and number 17 were not classified to only one category.

Each applicable muda question from check list is assessed, where: 0 means no waste; 1 means small waste; 2 means medium waste and 3 is big waste (serious). The results are presented in the graphical form (see figure 3).

Based on the assessment, for each identified "big waste" (preferably also medium) improvements measures must be elaborated. The usage of the presented approach allows to scan the remanufacturing process and order to identify areas with low performance. The results can be used as an input for the design of the improvement measures in the three dimensions of sustainability.

CONCLUSIONS

Application of the lean production methods and techniques gains recently a lot of interest among remanufacturers. The structure and characteristics of remanufacturing process is more complex than a production process for similar products. The existing examples of the industrial evidence and the academic research proofs that remanufacturer might benefit from application of the lean principles and toolbox. They also reported the constraints which are faced by the remanufacturers when applying lean approach. First of all it is difficult to scan the process and identify areas where reorganization of facility layout or different resources configuration are needed.

Presented by the author assessment approach is related to the operational level of lean concept. It allows to use the lean approach for identification of waste in the relation to sustainability dimensions: economic, ecological and social. The findings of this research will contribute to the development of the improvement measures for increasing the remanufacturing process sustainability.

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LEAN JAKO SPOSÓB NA POPRAWĘ PROCESU REMANUFACTURINGU

STRESZCZENIE. Wstęp: Lean production jest powszechnie wykorzystywaną koncepcją zarządzania, która pomaga przedsiębiorstwom dostarczać wartość dla klientów i redukować koszty. Obecnie budzi ona coraz większe zainteresowanie ze strony przedsiębiorstw zajmujących się remanufacturingiem (fabryczną regeneracją). W tym artykule przyjęto założenie, że proces remanufacturingu będzie miał wyższy poziom zrównoważonego wykorzystania zasobów jeżeli nie będzie w nim marnotrawstwa. Wdrożenie zasad i narzędzi lean production w procesie remanufacturingu może przynieść znaczne korzyści, równocześnie napotyka jednak wiele przeszkód, które zostały zidentyfikowane w tym artykule.

Metody: Przeprowadzono badania literaturowe, w tym celu przeszukano bazy Scopus, Science Direct and Business Source Premier databases dla kryterium "lean remanufacturing". Na podstawie analizy literaturowej dokonano identyfikacji problemów lean remanufacturing. Stworzone zostały ramy teoretyczne dla oceny procesu remanufacturingu z perspektywy zrównoważonego wykorzystania zasobów. Następnie dokonano analizy studiów przypadku, w celu identyfikacji poziomu szczupłości dla wybranych przykładów procesu remanufacturingu. Kolejnym krokiem badań była identyfikacja marnotrawstwa w celu wskazania obszarów kluczowych dla podniesienia poziomu zrównoważonego wykorzystania zasobów w procesie remanufacturingu.

Wyniki: W artykule przedstawiono teoretyczne rozważania na temat problemu oraz zdobyte doświadczenia praktyczne. Autorka omawia problemy lean remanufacturing. Analiza studiów przypadku została zrealizowana pod kątem oceny poziomu szczupłości procesu oraz identyfikacji obszarów wymagających usprawnień. Wyniki omówiono w kontekście wcześniejszych wniosków ze studiów literaturowych.

Wnioski: Proces remanufacturingu jest znacznie bardziej skomplikowany niż proces produkcji pierwotnej dla analogicznego produktu. Wdrożenia zasad i narzędzi lean production do procesu remanufacturingu jest na niższym poziomie niż w przypadku tradycyjnego wytwarzania. Jednak istnieją przykłady pochodzące z praktyki jak również studia teoretyczne dostarczające dowodów, że mimo licznych problemów i ograniczeń wdrażanie narzędzi lean może przynieść pozytywne efekty. Równocześnie istotne jest rozróżnienie lean remanufacturing na poziomie strategicznym i operacyjnym. Z perspektywy zrównoważonego wykorzystania zasobów bardziej odpowiednie wydaje się zastosowanie narzędzi i metod lean production na poziomie operacyjnym.

Słowa kluczowe: proces remanufacturingu, zrównoważone wykorzystanie zasobów (sustainability), lean production, eliminacja marnotrawstwa.

LEAN ALS VERFAHREN FÜR DIE VERBESSERUNG VON WIEDERAUFBEREITUNGSPROZESSEN

ZUSAMMENFASSUNG. Einleitung: Lean Produktion ist ein etabliertes Management-Konzept, welches den Unternehmen es ermöglicht, Werte für Kunden zu schöpfen und Kosten zu reduzieren. Gegenwärtig erweckt es ein immer größeres Interesse bei den Unternehmen, die sich mit dem Remanufacturing (fabrikmäßige Wiederaufbereitung) beschäftigen. Im vorliegenden Artikel ging man von der Annahme heraus, dass der Wiederaufbereitungsprozess bei der Ressourcennutzung nachhaltiger werden kann, wenn er keine Verschwendung von Ressourcen zulässt. Die Einführung von Prinzipien und Werkzeugen des Lean Production-Systems innerhalb eines Wiederaufbereitungsprozesses kann bedeutende Vorteile mit sich bringen, sie begegnet allerdings vielen Hindernissen, die in diesem Artikel identifiziert wurden.

Methoden: Die Forschungsmethodik beruhte auf einer Literaturrecherche, wobei man die Datenbasen von Scopus und Science Direct und Business Source Premier Databases in Anspruch nahm. Das Suchkriterium war dabei der Begriff "Lean Remanufacturing". Auf der Grundlage der Literaturanalyse wurden die Fragestellungen des Lean Remanufacturings ermittelt. Für die Beurteilung des Remanufacturingprozesses wurden angesichts der nachhaltigen und ausgewogenen Ressourcennutzung theoretische Rahmen erstellt. Ferner wurden Fallstudien für die Bewertung der "Schlankheit" von ausgewählten Beispielen des Wiederaufbereitungsprozesses durchgeführt. Ein nächster Schritt in diesem Forschungsvorhaben war die Identifikation von Verschwendungen. Das geschah zwecks der Ermittlung von Schlüsselbereichen, die für die Erhöhung des Niveaus einer nachhaltigen Ressourcennutzung im Wiederaufbereitungsprozess ausschlaggebend sind.

Ergebnisse: Im Artikel stellte man theoretische Erwägungen zum betreffenden Problem und die gewonnene praktische Erfahrung dar. Darin bespricht die Autorin also die Problemstellungen des Lean Remanufacturings. Die Analyse der Studienfälle wurde in Bezug auf das Niveau der Schlankheit des Prozesses und auf die Identifikation von verbesserungsbedürftigen Bereichen durchgeführt. Die Ergebnisse sind im Kontext der früheren Schlussfolgerungen von der Literaturrecherche kommentiert worden.

Fazit: Der Wiederaufbereitungsprozess ist komplexer als der primäre Produktionsprozess bei der Herstellung eines analogen Produktes. Die Umsetzung von Prinzipien und Werkzeugen der Lean Produktion innerhalb eines Wiederaufbereitungsprozesses geschieht auf einem niedrigeren Niveau als dies bei der traditionsgemäßen Erzeugung der Fall ist. Es gibt jedoch genügend Beispiele von der Praxis und Beweise von theoretischen Studien dafür, dass trotz zahlreicher Probleme und Einschränkungen die Einführung von Lean-Werkzeugen positive Resultate sichern kann. Gleichzeitig ist es nötig, die schlanke Wiederaufarbeitung auf operativer und strategischer Ebene zu unterscheiden. Aus der Perspektive der Nachhaltigkeit der Ressourcennutzung im Wiederaufbereitungsprozess scheint die Anwendung der Werkzeuge und Methoden von Lean Production auf der operativen Ebene mehr geeignet zu sein.

Codewörter: Schlanke Produktion, Verschwendung von Ressourcen, Nachhaltigkeit des Wiederaufbereitungsprozesses.

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