Remanufacturing: Challenges and Opportunities to be Lean

Jelena Kurilova-Palisaitiene and Erik Sundin
Department of Management and Engineering, Division of Manufacturing Engineering, Linköping University, Sweden

Abstract
The lean philosophy, which denotes business excellence through continuous improvement, originates from Japanese car manufacturer Toyota’s Production System (TPS). An area where lean is not fully explored is remanufacturing, a business that brings used products back to useful life. Remanufacturing is often a more complex process than manufacturing due to uncertainty of process steps/time and part quality/quantity.

This paper has explored remanufacturing by revealing its challenges and opportunities to be lean. The identified challenges to work with lean do not overcome the advantages of a lean remanufacturing system. Even though some research states that it is difficult or even impossible to apply lean to remanufacturing, this research recovers lean as a continuous improvement philosophy that not only works for manufacturing but also for remanufacturing.

Keywords:
Lean, Remanufacturing, Product Life-Cycle, Continuous Improvement

1 INTRODUCTION
The lean philosophy, which denotes business excellence through continuous improvement, originates from Japanese car manufacturer Toyota’s Production System. Lean requires a gradual and long-term approach and helps to maximize customer value and minimize waste. Working according to lean philosophy, companies start to see and understand the value of their own business [1]. Lean has been used for many years in manufacturing but has also spread to other areas, e.g. services and healthcare [2]. An area where lean is not fully explored is remanufacturing. Remanufacturers bring used products back to useful life. The remanufacturing process consists of several steps, e.g. inspection, cleaning, disassembly, reprocess, reassembly and testing (see Figure 1).

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 [3]. However, remanufacturing has a lot of similarities with manufacturing, and therefore applying lean production principles and philosophies to remanufacturing seems to be a logical step.

The growing need to deal with uncertainty and unpredictability challenges in order to sustain business is the major reason why many remanufacturers are interested in implementing lean at their facilities. Moreover, by analyzing manufacturers’ achievements and their competitive advantage gained through lean, remanufacturers are eager to investigate whether they have all the prerequisites to work with lean. For that reason, it is essential to study remanufacturing challenges and opportunities to be lean.

1.1 Aim
The aim of this paper is to explore remanufacturing by revealing its challenges and opportunities to be lean. Additionally, the comparison between remanufacturing and manufacturing is performed in order to identify the possible areas of improvements for remanufacturers in their quest to become lean.

1.2 Research Methodology
The research methodology consisted of a literature review, where research papers from the Emerald, Scopus, Science Direct and Business Source Premier databases were used. The search criterion was the phrase lean remanufacturing. In total 69 papers were found, among which 54 come from the Science Direct database. By disregarding the papers with the primary focus on sustainability and green logistics issues 26 papers were selected for further analysis. In addition, the author’s previous knowledge of lean literature was used.
1.3 Overview of the paper
First, constraints in remanufacturing are identified and summarized in three categories: product quality, lead time and inventory level.
The lean gap between remanufacturing and manufacturing is then visualized in a spider diagram. Following this, the advantages of lean remanufacturing are discussed and opportunities to be lean are revealed.
Finally, the results from the lean in remanufacturing industrial application and academic research are presented.

2 CONSTRAINTS IN REMANUFACTURING
2.1 Identifying remanufacturing constraints
The remanufacturing business is very young and immature in comparison with manufacturing. Manufacturing always comes first, since in order to remanufacture a product it has to be produced. Remanufacturers meet major business challenges, such as supply and demand balancing and process inefficiency and communication deficit. Nevertheless, the scope of remanufacturing expands; it does not avoid the classic mistakes of an immature business.

One of the first remanufacturing constraints identified is the incapability to reach the same level regarding the average manufacturers’ quality of products and lead time [4]. The first critical issues in remanufacturing come from shop floor constraints to satisfy customers’ needs: insufficient quantity of the cores, increased product variability, process bottlenecks, and product design-related problems, as well as low level of employee skills.

In order to control availability of the cores, Guide Jr. [5] introduced the characteristic of Material Recovery Rate (MRR). The intention was to make remanufacturing less dependent on variation in demand, quality, quantity and timing of incoming cores. However, MRR does help to control all remanufacturing issues. Remanufacturing is complex and difficult to manage due to a high number of uncertainties [6]. Absolutely, the core plays a central role, however even the remanufacturing process itself contributes to increased complexity. The issues of unpredictable and extremely long processing and waiting times, unknown number of required operations in process [3, 6 and 7], high level of inventory and deficit of the information about incoming cores [8] are vital to be solved in order to make remanufacturing a profitable business.

A critical moment is related to how uncertainty in the product life-cycle (see Figure 2) and product technological change influence the time and the number of incoming cores.

The obstacles in the product life-cycle return process and supply and demand constraints often force remanufacturers to cope with these problems alone, without any support from other actors of same product life-cycle [9, 10]. In fact, reverse logistics challenges are closely related to the supply chain, communication and collaboration challenges of the closed remanufacturing loop [12]. Poor information flow within the product life-cycle, multiple networks that interface poorly with one another and miscommunication concludes the identified remanufacturing list of constraints.

The major constraints in remanufacturing reveal that remanufacturers depend on the other, more mature product life-cycle actors, who dictates business rules. Being the last joint actor of the product life-cycle, remanufacturing has to adapt to the market conditions and make its contribution more obvious. It is a hard job to stay in the shadow of the much bigger product life-cycle actors, who started with the same kinds of challenges and business mistakes at least 100 years ago.

2.2 Classification of identified constraints
The 14 major remanufacturing constraints are identified and summarized in Figure 3. The interrelation of these constraints highlights three major categories of remanufacturing challenges: product quality, lead time and inventory level.
These groups of constraints are also known by manufacturers, who actively work toward enhancing product quality, shortening and standardizing lead time and minimizing inventory level in the factories.

Manufacturers have great experience in dealing with the same or similar challenges in remanufacturing. Therefore, it is reasonable to consider the methods that manufacturers employ while dealing with similar challenges. One of the most widely-used ways is to work with a philosophy of continuous improvement, also known as lean manufacturing or TPS.

Challenges in product quality, lead time and inventory level are those that a lean production system actively deals with. Therefore, it is suitable to consider a lean application to remanufacturing. Nevertheless, it is necessary to determine whether remanufacturing activities have the potential for lean improvements. In order to do so, the analysis of differences between manufacturing and remanufacturing in respect to lean is performed.

3 WHAT REMANUFACTURERS CAN LEARN FROM MANUFACTURERS

Sundin [3] highlights that although the differences between manufacturing and remanufacturing systems are very significant, they still have more in common than any other business processes. Moreover, it is necessary to distinguish how large the lean gap between remanufacturing and manufacturing is in regards to vital categories (see Table 2).

These 19 “critical to business” categories were collected during the literature review. However, the number of categories is limited to the research performed in the area of lean manufacturing and remanufacturing. These categories provide a solid platform for comparison of important remanufacturing and manufacturing business indicators.

Facing a very complex material flow, a very low level of automation, insufficient remanufacturing volumes, and an ineffective planning horizon resulting in extensive lead times, remanufacturers are lagging behind manufacturers. The difference between remanufacturers and manufacturers becomes more evident when comparing the level of uncertainty of the amount, quality and timing of incoming parts/cores as well as final goods.

Moreover, an absence of strong communication and information sharing channels, as well as a lack of collaboration between different divisions of manufacturing facilities and the rest of the product life-cycle actors, supports the evidence that remanufacturers have to learn a lot from manufacturers.

Table 2: Scores comparing manufacturing and remanufacturing in 19 categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Remanufacturing score value</th>
<th>Manufacturing score value</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue forecast</td>
<td>Very unstable/impossible to forecast</td>
<td>Variable/difficult to forecast</td>
<td>Stable/possible to forecast</td>
<td>Very stable/easy to forecast</td>
<td>2</td>
<td>3</td>
<td>[8, 13]</td>
</tr>
<tr>
<td>Costs</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
<td>3</td>
<td>2</td>
<td>[14, 15]</td>
</tr>
<tr>
<td>Competition</td>
<td>Very low</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
<td>2</td>
<td>3,5</td>
<td>[15]</td>
</tr>
<tr>
<td>Material flow</td>
<td>Very complex</td>
<td>Less complex</td>
<td>Simple</td>
<td>Very simple</td>
<td>1</td>
<td>2,5</td>
<td>[3]</td>
</tr>
<tr>
<td>Lead time</td>
<td>Very long/uncertain/variable</td>
<td>Long/predictable</td>
<td>Short/predictable</td>
<td>Very short/standard</td>
<td>1</td>
<td>3,5</td>
<td>[3, 5, 8, 15]</td>
</tr>
<tr>
<td>Volume</td>
<td>Very low</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
<td>1</td>
<td>3,5</td>
<td>[5, 8, 9, 13]</td>
</tr>
<tr>
<td>Automation</td>
<td>Very low</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
<td>1</td>
<td>3</td>
<td>[9]</td>
</tr>
<tr>
<td>Batch size</td>
<td>Uncertain/insufficient</td>
<td>Certain/insufficient</td>
<td>Standard/Sufficient enough</td>
<td>One-piece flow/perfectly sufficient</td>
<td>1</td>
<td>3,5</td>
<td>[9]</td>
</tr>
<tr>
<td>Planning horizon</td>
<td>No freeze window/bad planning</td>
<td>Ineffective freeze window</td>
<td>Effective freeze window</td>
<td>Very effective freeze window combined with JIT</td>
<td>2</td>
<td>3,5</td>
<td>[16, 17]</td>
</tr>
<tr>
<td>Product variation</td>
<td>Very high/difficult to forecast</td>
<td>High/possible to forecast</td>
<td>Customised/possible to forecast</td>
<td>Customised and module-based/standard</td>
<td>1</td>
<td>2,5</td>
<td>[3, 5, 9, 15, 18]</td>
</tr>
<tr>
<td>Design for Remanufacturing (DFRRem)</td>
<td>Very low</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
<td>1</td>
<td>1</td>
<td>[3, 9]</td>
</tr>
<tr>
<td>Inventory</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
<td>2</td>
<td>2,5</td>
<td>[8, 15]</td>
</tr>
<tr>
<td>Yield</td>
<td>Very low/uncertain</td>
<td>Low/predictable</td>
<td>High/predictable</td>
<td>Very high/predictable</td>
<td>1</td>
<td>2,5</td>
<td>[3, 5, 15]</td>
</tr>
<tr>
<td>Quantity</td>
<td>Very uncertain</td>
<td>Difficult, but possible to forecast</td>
<td>Easy to forecast</td>
<td>Standard and stable</td>
<td>1.5</td>
<td>3,5</td>
<td>[5, 9, 19, 20]</td>
</tr>
<tr>
<td>Quality</td>
<td>Uncertain/bad</td>
<td>Certain/insufficient</td>
<td>Good/sufficient</td>
<td>Very good/standard</td>
<td>1.5</td>
<td>3,5</td>
<td>[5, 13]</td>
</tr>
<tr>
<td>Timing</td>
<td>Very uncertain</td>
<td>Difficult, but possible to forecast</td>
<td>Easy to forecast</td>
<td>Standard and stable</td>
<td>1</td>
<td>3</td>
<td>[5]</td>
</tr>
<tr>
<td>Communication</td>
<td>Not functioning</td>
<td>Functioning in a shop floor scope</td>
<td>Functioning in a company scope</td>
<td>Functioning in a product lifecycle scope</td>
<td>1</td>
<td>3</td>
<td>[21]</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Not functioning</td>
<td>Functioning in a shop floor scope</td>
<td>Functioning in a company scope</td>
<td>Functioning in a product lifecycle scope</td>
<td>1</td>
<td>3</td>
<td>[21]</td>
</tr>
<tr>
<td>Sharing risk</td>
<td>Not functioning</td>
<td>Functioning in a shop floor scope</td>
<td>Functioning in a company scope</td>
<td>Functioning in a product lifecycle scope</td>
<td>1</td>
<td>3</td>
<td>[21]</td>
</tr>
</tbody>
</table>
The gap between manufacturing and remanufacturers with respect to lean becomes more evident by looking at Figure 4.

Manufacturers have not fully accomplished their transformation to the lean production system yet. Remanufacturers have a great potential for improvement to reach the level manufacturers have today. In 17 of 19 categories, remanufacturers are far behind manufacturers. The gap is relatively large, and will continue to increase every day, since manufacturers continuously working on production improvements.

The only characteristic where remanufacturers lead manufacturers is in the area of cost. As previously stated, low cost does not attribute to the state-of-the-art business, but rather mainly points to cheap raw material. At the same time, the only characteristic where manufacturers perform poorly is Design for Remanufacturing (DFRem). Manufacturers tend to increase product variation, and this means that remanufacturers will deal with more challenges in the future.

The situation can become even worse if the inefficient communication and collaboration between remanufacturers and the other product life-cycle actors continues. Risk sharing is not practiced at all, since there is no system of shared values yet developed in the product life-cycle.

One of the reasons for a higher score in manufacturing is their achievements in developing an efficient production system and collaborative company culture of continuous improvements. As mentioned before, a lean manufacturing system with its operational principles and strategic philosophies helps manufacturers to achieve the desired improvements.

Manufacturers are the pioneers of lean transformations, so today it is not only entire production facilities, but also global corporations that work according to lean principles and philosophy. These companies gradually succeeded in enhancing product quality, reducing lead time and controlling inventory level. Lean principles and tools can help remanufacturers gain competitive advantage, as they did for manufacturers.

4 LEAN IN REMANUFACTURING

The earlier attempts to apply lean in remanufacturing were challenged by the major remanufacturing constraints (see Figure 3). The authors claim that stable demand and supply are the prerequisites to work with lean. Some researchers have expressed their deep concern about the transformation of lean manufacturing systems into lean remanufacturing; the claim that establishing the types of lean and mass customization systems that manufacturers depend on is practically impossible [8].

However, the skepticism regarding lean implementation in remanufacturing drives researchers to investigate the possibility to apply lean to remanufacturing. Since the start of remanufacturing activities, researchers and practitioners have developed different methods for planning, scheduling and controlling remanufacturing systems. For example, Guide Jr. [22] proposed the drum-buffer-rope planning system, which reminds remanufacturers about the pull system, actively used by lean manufacturers.

Moreover, the potential for applying lean to remanufacturing has been noted by several researchers (see Table 2). The definite need for improvements in the remanufacturing business was studied by Sundin [3]. He identified a need for remanufacturing to gain efficiency through several lean production concepts, such as lowering the high level of inventories, material movements, product flow and use of space.

Fargher [23] provided an explicit finding on the application of lean tools in remanufacturing. At the same time, Jacobs et al. [24] introduced lean as a tool for waste reduction in remanufacturing, and stated that a signal for production is a customer pull. Therefore, lean can help remanufacturers to decrease lead time, costs, increase productivity, enhance quality, and make a continuous flow.

Later, Östlin and Ekholm [25] provided practical evidence on the benefits of lean production in remanufacturing. Here, the lean concept is actively treated as a set of tools and principles that help remanufacturers to increase productivity, decrease lead time and costs, enhance quality, develop flexibility in production, reduce setup time and rearrange workshop layout.

Hunter and Black [26] provide another example on successful implementation of lean tools in cellular remanufacturing, and point out four critical control functions in lean production: quality, production, process and inventory.

Kucher [27], in his long-term observations of lean principles in remanufacturing, concluded that there is great possibility to adjust an application of lean tools
depending on the levels of product variety and volume in remanufacturing. Kanikula and Koch [28] developed nine Kanban replenishment scenarios including inventory management, pull system, First In First Out (FIFO) and supermarket-controlled buffer in remanufacturing.

In the finding of the previously mentioned remanufacturing researcher’s lean production philosophy and principles, it indeed helps remanufacturers enhance products quality, shorten lead time and reduce inventory level. Moreover, lean provides a guideline for value creation in every process.

However, all of these attempts to apply lean principles and tolls in remanufacturing belong to so-called “operational lean production” [29]. In this case, lean is usually seen as a collection of different improvement initiatives and projects to improve separate remanufacturing problems once at a time. There is usually a weak connection between lean implementation and a company’s managerial strategy. Here, the lean concept is usually mistrusted by the one who executes it, destroying any base for continuous improvement.

Therefore, it is noticed that lean is not only a set of tools, but rather a company’s culture and management philosophy. This is in contrast to operational companies, which work on a strategic lean philosophy level and succeed to insert lean thinking to the corporate culture [29]. These types of companies usually create their own production management systems by adopting lean thinking and transforming the lean practical examples of the manufacturing pioneers. Often, companies gradually move from the lean operational to strategic level. However, some companies never develop a lean philosophy and culture, and therefore fail to transform into a profitable lean company. Lean proved to be a philosophy of gradual improvement, and this fact should not be underestimated by its implementers.

The strategic level in lean application is the missing part of lean research and implementation in remanufacturing. That is why the long-term result of lean application in remanufacturing is so difficult to spot. It is necessary to insert the lean culture of continuous improvement and lean values into the remanufacturing business, and manufacturers should help remanufacturers to do that.

5 CONCLUSIONS

The need to improve vital indicators of the remanufacturing business is revealed. The major remanufacturing challenges are identified and classified into three categories: product quality, lead time and inventory level challenges.

Lean production principles and philosophies successively deal with all three of these groups of challenges. This finding leads to an assumption that lean can help remanufacturing to improve its business indicators, and therefore gain a competitive advantage as it did for manufacturers. Since the remanufacturing business has many similarities with manufacturing, it is reasonable to make a comparison between manufacturers and remanufacturers with respect to lean.

Remanufacturers have opportunities to be lean in 19 identified categories (see Figure 4). The gap between remanufacturers and manufacturers appears to be big. In 17 of the 19 vital characteristics for sustainable business, remanufacturers are behind manufacturers. The only characteristic where remanufacturers have a leading position is cost. However, low cost does not result in high revenue and mainly points to cheap raw material and returned cores. Therefore, the gap between remanufacturers and manufacturers provides evidence that remanufacturers can learn a lot from manufacturers while becoming leaner.

The advantages of lean remanufacturing are discussed and possibilities to be lean are presented. Findings from industrial evidence and academic research on lean remanufacturing provide a solid base for further investigation of lean application benefits to remanufacturing. However, lean remanufacturing principles and methods should not be underestimated, but rather modified in order to suit remanufacturing business needs. Moreover, a lean remanufacturing deployment strategy should avoid deploying lean on a project basis, but rather treat it as a company’s culture of continuous improvement.

The findings of this research will contribute to the future development of a lean model with principles and philosophies designed exclusively for remanufacturing.

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REFERENCES


