Current State and Future Perspective Research on Lean Remanufacturing – Focusing on the Automotive Industry

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Abstract. *Remanufacturing, as one of the most promising product recovery options, is influenced by the uncertainty involved with incoming cores. This poses different organizational and technical challenges to those found in conventional manufacturing. Finding the right strategy is very important to make business more effective and profitable. The combination of remanufacturing and lean manufacturing offers a good opportunity to increase process efficiencies in remanufacturing industry. This paper reviews the current state of practice of lean manufacturing philosophy in the automotive sector, together with an identification of needed further research.*

Keywords: *Remanufacturing Process, Lean Remanufacturing, Uncertainties*

1 Introduction

Increased awareness of environmental degradation has precipitated legislative requirements that have drawn attention to product recovery options such as remanufacturing, reconditioning and repair. Of these options, remanufacturing is the only one with which a used product can be brought back to a condition at least equal to that of a new product in terms of quality, performance and warranty (Ijomah 2002).

As such, remanufacturing represents a good opportunity for sustainable development. It retains not only the raw material - as is the case with recycling - but it can also keep a large part of the value added to the raw material during the original manufacturing process. Retaining the shape of raw material avoids the need for further manufacturing processes that are $C0_2$ emitting(Giuntini and Gaudette 2003, Ijomah 2008) and, at the same time, provides significant energy savings by using remanufactured components that require 50-80% less energy to produce than newly manufactured parts (Lund 1984). In addition, remanufacturing creates a new market for employment.

According to Golinska and Kawa (2011) the automotive industry is recognised as one of the most environmentally aware manufacturing sectors. This is illustrated by the fact that around 90% of the total worldwide remanufacturing industry belongs to this sector (Kim and Selgier 2006).

This article examines lean remanufacturing practices within the automotive industry by describing the remanufacturing process and its key problems. In addition, the lean manufacturing approach within a remanufacturing context is reviewed. A case study based on an automotive remanufacturing company is presented to illustrate the current state of the research in the application of lean manufacturing within the remanufacturing industry (both positive and negative implications are identified). Finally, the paper ends with conclusions and provides recommendations for future research priorities and directions related to the application lean remanufacturing approach.

2 Remanufacturing Process

The remanufacturing process usually begins with disassembling used products, known as 'cores', into components, which are then cleaned, inspected, and tested to verify that they meet the required quality standards to be reused without further work. Those that do not meet the requirements can be reprocessed via remanufacturing. If this is not possible due to technological issues or economic reasons, the substandard components are put towards other product recovery options - i.e. recycling - and are replaced with new parts. The remanufactured parts are then reassembled - often together with new parts - into the product (Giuntini and Gaudette 2003). Depending on the product type and volume required, the remanufacturing steps presented above can be undertaken in a different sequence or some may be omitted if the circumstance permits. For example, inspection can be done before the disassembly and cleaning in order to detect damages and select cores that cannot be remanufactured (Sundin 2004). However, some general characteristics remain valid in every remanufacturing process. For example, disassembly always precedes reprocessing and reassembly always succeeds disassembly (Östlin 2008). Figure 2 presents the possible steps (in no specific order) that can be taken during the remanufacturing process.

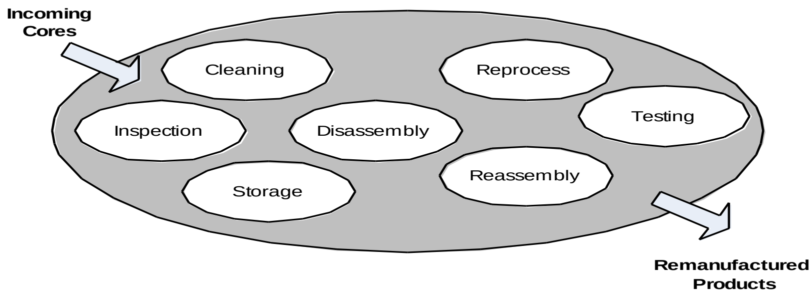

Fig. 1. The generic remanufacturing process. (Source: Sundin 2004)

Within the remanufacturing process, managers have to deal with organisational and technical challenges different from those found in conventional manufacturing. The remanufacturing process is inherently influenced by the uncertain condition of the used product e.g. dirt, wear and missing components. Though the arriving cores may be made of the same components, the operations and time required to remanufacture each item will be unique to its condition, while some operations may not be necessary at all. Additionally, the quantity of new components required will depend on the quality of cores - the primary source for supplying remanufactured parts (Giuntini and Gaudette 2003). The significant level of uncertainty in the quality of incoming cores is not the only problem that makes planning and controlling the remanufacturing process more difficult. It is difficult to predict when products will stop fulfilling customer needs, therefore it is often difficult to exactly ascertain the timescale for acquiring necessary cores. This makes the remanufacturing process less predictable than conventional manufacturing (Lundmark at al. 2009). The variability of products is another challenge that occurs in the remanufacturing process in the automotive industry. This is the result of continuous upgrading of the products due to the use of new solutions and technologies or the elimination of design errors (Seitz 2007). In addition, since products are not typically designed for disassembly, the remanufacturing process is more complex. Components that were in good condition can be damaged during the disassembly operation, resulting in higher operational costs (Giuntini and Gaudette 2003). As a result, current remanufacturing processes are more complex and less predictable than conventional manufacturing and require high levels of inspection and testing to achieve high quality products. This can lead to higher remanufacturing costs and longer remanufacturing lead-times. Therefore it is important to find the right strategy to make the remanufacturing process cost effective and thereby contribute to the overall profitability of the remanufacturing business.

3 Lean Manufacturing

One way of overcoming the difficulties involved with the remanufacturing process and increase both efficiency and productivity is to apply the principles, tools and methods of lean manufacturing (Seitz 2007, Kucner 2008). Though lean manufacturing philosophy has its roots in the automotive manufacturing industry, Womack and Jones (2003) state that the principles of this approach can be successfully applied to other sectors. They highlight the principles that define lean thinking as (2003):

- *precisely specify* ***value*** *by specific product;*
- *identify the* ***value stream*** *for each product;*
- *make value* ***flow*** *without interruptions;*
- *let the customer* ***pull*** *value from the producer;* and
- *pursue* ***perfection.***

The entire range of lean manufacturing tools and methods were developed for the practical application of lean thinking. Those tools and methods include: Value Stream Mapping to help generate ideas for process redesign; 5S that allows effective organization of work area; and Kanban, which limits work in process and regulates the flow of goods between the factory, suppliers and customers.

4 Lean Remanufacturing

The application of the lean manufacturing approach within a remanufacturing context - Lean Remanufacturing - has only recently gained the attention of researchers and practitioners. Hence, there is little literature on this subject. The combination of remanufacturing and lean manufacturing offers a good opportunity to increase process efficiencies within the remanufacturing industry (Seiz 2007, Kucner 2008).

The first reported study is a case study conducted by Amezquita et al (1998) that focuses on an independent automotive remanufacturer and specifically analyzes the process of remanufacturing clutches. Their analysis shows how the lean manufacturing approach can enhance the effectiveness of the remanufacturing process by developing techniques for lean automation and different methods for the reduction of setup times. Fargher (2003) states that lean manufacturing applied to the remanufacturing operations brings various benefits thanks to the identification and elimination of non-value-added activities through continuous improvement. These benefits include (Seitz 2007):

- Reduction of lead-time;
- Reduced work in process;
- Improved on-time shipments;
- Reduced floor space; and
- Improved quality.

5 Research Methodology

The research addresses efforts to improve the remanufacturing process through the application of lean manufacturing practices. As a relatively new topic, there is limited understanding of lean remanufacturing. In order to identify key research challenges and needs within this immature research area we must first understand the current state of the application of lean manufacturing within the automotive remanufacturing industry. A case study is a relevant research strategy that enables a rich understanding of the research context as well as the process being enacted (Saunders et al. 2003). In this instance, the case study took place in an automotive remanufacturing facility in the United Kingdom. During the visit, observation of the shop-floor and semi-structured interviews with Managers were conducted.

5.1 Case Study

In order to achieve a better understanding of the lean manufacturing approach within an automotive remanufacturing context, a case study was undertaken. The study is limited to analysis of operational shop-floor activities (focusing on the application of shop floor tools) in automotive remanufacturer, Caterpillar Remanufacturing Ltd (CatReman). Three types of products are remanufactured at CatReman: engines, turbines, and turbochargers. Lean manufacturing methods were first introduced into the company in 2005 and since then the principles and tools have been gradually implemented on a broader scale.

Case Study Findings.

CatReman started their lean application by introducing a lean manufacturing tool called Visual Control[1] within the facility's most critical areas. Thereafter, the lean approach was implemented within the whole facility, starting with creating current and future state Value Stream Mapping[2], before tools and methods - Pull system[3] (only from customer) and Overall Equipment Effectiveness[4] - were applied. The facility also implemented Total Productive Maintenance[5] for critical machines and is working towards this for all major machinery.

Visual Control is of particular importance for CatReman during the visual inspection process. According to Errington (2009) the inspection step is crucial for remanufacturing. The incorrect assessment of a core or component can cause unnecessary additional operational costs. As remanufacturing is strongly affected by variation in products, those tasked with assessment require precise knowledge of each variation. At CatReman, visual boards are employed that display sample components and give visual and written descriptions of the critical areas for inspecting as well as the acceptable criteria. They are located near to the inspection, machining and the assembly areas, which also have standard worksheets giving the employees the same information. This means that if an operator is unsure of whether the component he or she receives is good enough to remanufacture, he or she can check it at the visual display board. This also serves to remind operators of the importance of quality.

CatReman is also using other forms of visual display boards, such as section (display metrics specific to the section in which they are located) and facility boards (display metrics for the whole facility) to measure, communicate and control the following metrics: people (largely safety and training); quality (warranty to sales, test rejects, etc.); speed (on time delivery, performance to TAKT time etc.) and cost (unplanned overtime, etc.). The top ten most common defects are also presented on the section metrics boards. All of these visual control tools are used to aid the machine operator in the lean process and act as a reminder of the most prevalent quality issues as part of general communications.

Moreover, the plant's layout was significantly changed to be more lean. Employees have a meeting with managers every day, in which they discuss the previous day's

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[1] Visual Control – '*is any communication device used in the work environment that tells us at a glance how work should be done and whether it is deviating from the standard'(Liker,2004)*

[2] Value Steam Mapping –'*captures processes, material flows, and information flows of a given product family and helps to identify waste in the system.'(Liker, 2004)*

[3] Pull system – '*the preceding process must always do what the subsequent process says' (Liker, 2004)*.

[4] Overall Equipment Effectiveness – '*a measure of equipment uptime'(Liker, 2004)*

[5] Total Productive Maintenance - method for improving availability of machines through better utilization of maintenance and production resources

production and the coming days production, and disseminate any local or corporate information, such as visits to the factory. There was also the opportunity for employees to voice comments and give feedback to their manager. Each identified problem is investigated and resolved by using the Ishikawa diagram, 5 why and histograms[6]. These activities have improved the operations within CatReman by:

- Reducing work in process;
- Increasing production control; and
- Providing better service (to increase ability to meet deadlines).

The facility metrics show the benefits of lean manufacturing and are reported corporately each month.

Despite the advantages gained from implementing lean manufacturing tools and methods identified above, it was observed that not all lean tools and principles were easily and successfully applied within the remanufacturing context of CatReman.

The pull system within operations is difficult to apply because of the high variability and low repeatability of products. It is also hard to use takt time[7] due to the uncertain condition of cores. Components have to go through different operations to meet the required specification. Some of them will require more time to pass each step and in some cases some operations will be omitted. Additionally, the uncertain condition of components (particularly unique ones) might cause a delay in the reassembly step, because of the need to wait for new components. Because of the high variability of products it is not cost effective to keep stock of all new components that may be needed. However, it was observed that there was a high inventory level of used products. This is a result of the uncertainty in the quantity and timing of incoming cores, i.e. difficulties in predicting the types of cores and when they will arrive at the facility. During the interviews it was found that implementation of 5S is also difficult, since operations on the various components are carried out at the same workplace. As a result, there is a need to keep many different tools at a workstation, not all of which are required regularly. However, reducing the number of tools can cause waste in motion as a result of continuously picking up tools from the store when required. Returned products are usually dirty and this also makes it difficult to keep workplaces clean.

The interviews with Managers identified that Caterpillar has implemented Standard Operating Procedures[8] for all remanufacturing operations - some general (for example for cleaning and inspecting bolts) and some specific to a particular product (for example remanufacturing a cylinder head). They also have Standard Operating Procedures (SOPs) for other processes such as machine maintenance and daily operator checks. This means they can give SOPs to the operator but if additional salvage is required they can not cover it this way. A part might need additional (and not necessarily cost-effective) work because it is not possible to buy new parts (the engine is not in current

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[6]Ishikawa chart, 5Why, histogram – are problem solving tools.
[7] Takt time – '*time required to complete one job at the pace of customer demand',(Liker, 2004)*
[8] Standard Operating Procedures – Documented procedures that capture 'best practice'

production) or because the lead-time for the new part is so long. In cases such as this, sometimes other similar used parts are adapted to make the part that is required - breaching SOPs. In this way, SOPs mitigate some of the problems but are not entirely effective.

6 Conclusion

The literature review and case study results have confirmed that the lean manufacturing approach brought some important benefits to the automotive remanufacturing sector. On the other hand, the case study also identified that some of the lean manufacturing tools and methods cannot be implemented successfully within automotive remanufacturing operations. Moreover, it was identified that the uncertainty involved in incoming cores (particularly with quality) might be the key problem in the application of the lean manufacturing tools within an automotive remanufacturing shop floor. A similar observation was reported by Östlin and Ekholm (2007)[9] based on their analysis of the toner cartridge remanufacturer company, Scandi-Toner AB. It was observed that the variable processing times and uncertainties in materials recovered limited the implementation of a lean manufacturing approach within that remanufacturing context. As variable processing times are a result of uncertainty in the quality of incoming cores (Lundmark et al. 2009) and the same can be said about the uncertainties in materials recovered, the conclusion might be drawn that uncertainty of incoming cores might be one of the main negative factors for the application of lean manufacturing tools within the remanufacturing context – for every type of product. Despite the fact that difficulties that occur within the remanufacturing process are product type-dependant (Sundin 2004), factors that limit implementation of lean manufacturing arise from its origins. Lean manufacturing has its roots in the Toyota Production System and was developed in the conventional manufacturing sector where uncertainty involved with input is not such an important issue. The lean manufacturing approach was not developed to apply to the variable conditions of remanufacturing. The implementation of some of the principles and tools of lean manufacturing within remanufacturing may require adapting to changeable cores or the elimination of identified constraints. This study provided empirical evidence that identified both positive and negative implications of the role of lean manufacturing within remanufacturing context. However, to make any step to improve lean remanufacturing application, one must acknowledge that one case study is not sufficient and more research is necessary. In particular, there is a need to confirm if uncertainties are indeed the main constraint. Identifying other factors that limit implementation and classifying their relative significance would achieve this.

[9] An analysis of the possibility of implementation lean manufacturing methods within toner cartridge remanufacturer.

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