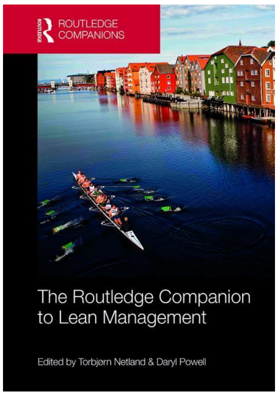

The Routledge Companion to Lean Management

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Lean Remanufacturing

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LEAN REMANUFACTURING

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Introduction

"How do I apply lean methods in my remanufacturing organization?" is a question many executives and managers ask themselves. Since the literature on using lean tools in production environments is usually focused on original equipment manufacturers (OEMs), its application in commercial remanufacturing is often unreported. This chapter fills a gap in the literature with a brief overview of how remanufacturers can translate manufacturing-oriented lean tools and principles into their processes. The authors also discuss the challenges and opportunities that are peculiar to lean remanufacturing operations.

What is Remanufacturing?

Continued strains on the planet's resources, limited sites for product disposal, and the introduction of new environmental legislation have resulted in a growing interest in material and product recovery options. One of the most promising and cost-effective options for establishing a low-carbon, circular economy is remanufacturing, which can bring back end-of-life products to an as-good-as-new condition in terms of quality, performance, and warranty (Ijomah et al., 2007). Usually, the process starts from the initial cleaning of used products (called cores), which are often dirty, to allow accurate assessment of their condition (Ijomah et al., 1999). Then, cores are disassembled so that individual components are obtained, cleaned, and carefully inspected to verify that they meet the required quality standards. Very often inspection is not a separate operation but rather carried out during the disassembly step. Those that do not meet expectations can be reprocessed via remanufacturing. Remanufacture of the components includes all activities that would bring worn parts to at least the original OEM specification (for example, surface grinding, welding, etc.). If this is not possible due to technological issues, economic reasons, or safety restrictions, the substandard components are put toward other product recovery options—i.e. recycling—and are replaced with new parts. When all required components are collected (including remanufactured parts and new components), the product can be reassembled. The entire product must then pass a final test to ensure that quality is at least equal to a newly manufactured, equivalent product. Figure 16.1 represents the remanufacturing process.

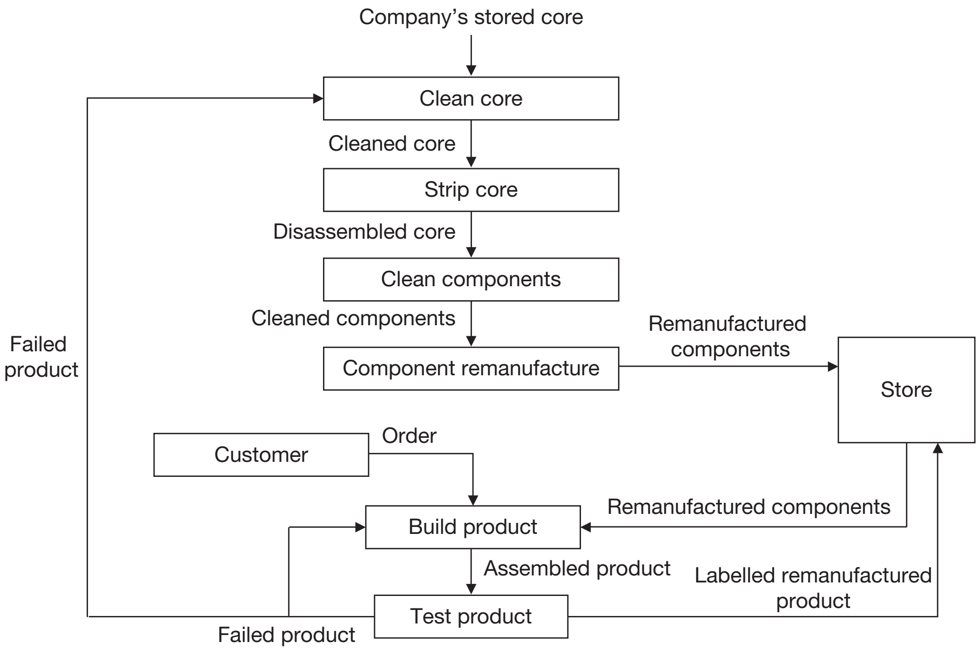

Figure 16.1 Generic remanufacturing process chart

Source: Ijomah (2002).

The remanufacturing process differs from conventional manufacturing. Thus, remanufacturers face different challenges from those experienced by conventional manufacturers. As such, Guide (2000) distinguishes the major challenges that influence and complicate production planning and control activities within the remanufacturing industry. These are explained below.

Uncertainty in the Timing and the Quantity of Returns

The product returns are highly uncertain in terms of time and quantity of available cores for remanufacturing, which is mainly caused by the uncertain nature of the life of the products. The fact that the numbers and delivery times of returned cores cannot be controlled by remanufacturers forces them to keep a higher level of inventory to protect against the variability in supply and demand.

Need to Balance Returns with Demand

To avoid excessive inventory, which generates costs, while simultaneously having sufficient stock to meet customer expectations, remanufacturers have to balance returns and demand rate. It requires extra effort that includes not only core acquisition (which includes identifying the potential source of cores, establishing preferences, etc.), but also coordination in the purchasing of replacement parts that are dependent on the expected volume and condition of cores. Moreover, all of the production decisions regarding resource planning also depend on core acquisition and timing.

Disassembly of Returned Products

Returned product has to be disassembled first, before being handed to the next remanufacturing operation. The result of this stage impacts on many activities such as purchasing new components, scheduling and resource planning. It becomes even more difficult when the products have not been designed with disassembly in mind, as components can be damaged or destroyed during disassembly. This leads to less predictable material recovery rates and generates more waste. Moreover, as there is no evidence that existing automated techniques can be used during disassembly, this also makes this task very labor intensive with highly variable processing times.

Uncertainty in Materials Recovered from Returned Items

The remanufacturers have to acquire the replacements for parts that cannot be reused from cores. The process is further complicated because it is difficult to predict the rate of material recovery before the product is disassembled. For example, two identically returned items may contain very different sets of parts that are either currently in the expected condition or can be returned to it.

Requirement for Reverse Logistics Network

This challenge addresses the requirements regarding the collection and movement of goods from end users to remanufacturers. A number of decisions have to be made that involve the number and location of take-back centers, the transportation method, etc.

Complication of Material-matching Restrictions

Complicated material-matching requirements define the situation whereby some products have their own unique serial and part number, and it is important to reassemble the same components. Moreover, sometimes products remain in the possession of customers who require the same unit to be returned. This complicates resource planning, shop floor control, and material management.

Routing Uncertainty and Processing Time Uncertainty

This is a consequence of the different condition of cores. The same components taken from different products might require different processes to be recovered and even different degrees of treatment for these operations. The condition of the components is dependent on both user habits and the repair, remanufacture, or reconditioning history. Very often, such activities are carried out without adhering to a specification, which results in mistakes such as wrongly painted surfaces. The consequential effect is more operations and time required to correct the mistakes.

These make the remanufacturing process less stable and less predictable than conventional manufacturing and require high levels of inspection and testing to achieve high quality products. This can lead to higher costs and longer remanufacturing lead times (Pawlik et al., 2013). Despite the existing challenges, remanufacturing has experienced rapid development during the past decade.

Lean Remanufacturing

The application of the lean manufacturing approach within a remanufacturing context—termed "lean remanufacturing"—has only recently gained the attention of researchers and practitioners (Pawlik et al., 2013). However, although slim, the reported work does suggest that the combination of remanufacturing and lean principles offers a good opportunity to increase process efficiencies within the remanufacturing industry (Kucner, 2008). A significant component of lean is the concept of value. Therefore, it is important to reconsider the commonly held paradigms of the value-added and non-value-added activities with regard to the remanufacturing context. There is a need to take a bigger-picture view of the value of waste, as what might be considered waste by a customer is actually valuable for the remanufacturing business. Remanufacturing is clearly adding value to the products, which were meant to be discarded in terms of life cycle value. However, it is important to look closely into the inefficiencies that occur during the process.

Excess inventory is one of the most significant wastes in remanufacturing. Indeed, most remanufacturers report that they struggle with the excess inventory of cores, work in process (WIP), and remanufactured products. Remanufacturers do not have influence over when a product will be returned to the facility, therefore forcing them to keep a higher level of the inventory against the variability in supply and demand (Guide, 2000). In many instances, the remanufacturers don't examine and refresh their inventories to remove the obsolete products. They want to keep them "just in case." Moreover, because the quality of the components can only be uncovered when the product is disassembled, remanufacturers prefer to do that early in the remanufacturing process which results in high WIP (Kucner, 2008). In addition, the uncertain quality of the components results in imprecise estimates of the times required to carry out operations. As a strategic buffer against this variability, many remanufacturers maintain significant-level inventories between operations.

In remanufacturing, some of the operations do not add value. Indeed, it has been observed that a higher percentage of operations that transform the product (but do not add value for the final customer) occur in remanufacturing than in conventional manufacturing. For example *inspection*, being a crucial stage for the remanufacturing process (Errington and Childe, 2013), has been identified as adding no value (Kucner, 2008). This is unfortunate because remanufacturing always requires 100 percent inspection, in contrast to conventional manufacturing where sampling methods are often used (Brent and Steinhilper, 2004). Another essential step in the remanufacturing process, *disassembly,* has been identified as an operation that is not adding value for the final customer and indeed might even be seen as a reduction of the inherent value of used products (Kucner, 2008).

Compared with the literature on conventional manufacturing, there is relatively little in the academic literature relating to the application of lean to remanufacturing. The first reported study of lean remanufacturing was presented by Amezquita and Bras (1996), which focused on an independent automotive remanufacturer of automobile clutches. This research compared a remanufacturing process that contains traditional craft and mass production practices with lean remanufacturing practices. One major benefit observed was the elimination of the non-value-added operations, resulting in enormous cost savings. Indeed, this research shows that the effectiveness of the remanufacturing process can be improved through the development of lean automation techniques.

Kucner (2008) claims that lean production tools and techniques can be applied to remanufacturing; however, there is not a single "best" lean solution. Specific solutions must be tailored to particular remanufacturing contexts. He examined four types of remanufacturing process, ranging from high product variability to low product variability. In each of these case studies the implementation of lean methods significantly improved performance, particularly in developing internal process stability, built-in quality, and just-in-time production. Fargher (2007) and Pawlik et al. (2013) also confirmed that the application of lean manufacturing within remanufacturing operations can bring significant benefits including a reduction in lead time, reduced WIP, improved on-time shipments, increased utilization of floor space, improved quality, and increased production control (Pawlik et al., 2013).

Sundin (2006) used the "rapid plant assessment" tool—a unique assessment tool used to assess plant performance, which helps to identify where the opportunities for improvement are—to conduct case studies in five companies (from different remanufacturing sectors). The results of this work showed that the investigated remanufacturers performed well in the following categories: "customer satisfaction," "people teamwork," "skill level and motivation," "ability to manage complexity and variability," and "quality system development." He identified also that, in most companies, categories such as "visual management deployment," "product flow," "space use," "material movements," together with "inventory and WIP level," presented below-average or poor performance and needed to be improved to make the company more "lean."

With regard to material flow, Hunter and Black (2007) investigated cellular layout in remanufacturing. They proposed a cellular layout for the recovery of product environment and claim that this solution can help to achieve a higher level of productivity and increased quality of remanufactured products. However, to maintain the flow and be able to use cellular layouts in remanufacturing, it is important to supply sufficient volume and frequency of return products (one of the remanufacturing challenges). Other researchers have also noticed existing restrictions and difficulties with the application of established lean tools and methods within the remanufacturing environment. Pawlik et al. (2013) identified that in the automotive sector, the uncertainties involved with incoming cores are a key issue influencing the probability of successful implementation. A similar conclusion was reported by Östlin and Ekholm (2007) regarding a toner cartridge remanufacturer. It was observed that the variable processing time and uncertainties in materials recovered limited the implementation of lean approaches. Moreover, Amezquita and Bras (1996) noticed that because of the stochastic nature of returned products, traditional remanufacturing processes are difficult to standardize.

Although there is relatively little in the academic literature relating to the application of lean philosophies to remanufacturing, practitioners do appear to be exploiting the concepts where possible. Indeed, some of the companies, particularly OEMs, are obligated to introduce lean within their facilities according to corporation policies and procedures.

Challenges and Opportunities

The main aim is to focus on challenges and opportunities within the processes and areas where a different view is required compared with conventional manufacturing. A more complete picture is presented, briefly discussing the similarities between different areas. Many people perceive lean as a set of tools and principles for eliminating waste, forgetting that "people are at the center of the Toyota Production System house" (Liker et al., 2008). Engaging all individuals is crucial in driving continuous improvement. Creating a lean culture in the organization requires strong leadership with managers who understand the lean concept, coupled with the will and capability to move forward. Within a remanufacturing environment, it was frequently observed that managers believe the lean concept is applicable only to conventional manufacturing. Consequently, the diverse problems arising in remanufacturing environments (described earlier in this chapter) coupled with a lack of, or at least limited, knowledge of the opportunities for application of lean in their operations discourage managers from beginning lean initiatives. However, this is an unnecessarily negative view. The following section reviews the challenges and opportunities of applying lean tools in remanufacturing operations.

The 5S method is often a starting point for that journey (Petersson et al., 2010). This is a process that allows managers to create a well-organized and functional workplace where there is a *place for everything and everything in its place.* The primary purpose of the first "S" is to sort the tools and materials within the workplace in order to separate those frequently used from those rarely or never used. However, in remanufacturing where there is a higher variety of products compared with conventional manufacturing, this approach results in a need to keep many different tools in the workplace. Reducing the number of tools can cause *waste in motion* as a result of frequently needing to pick up tools from the store when required (Pawlik et al., 2013). Uncertainty in the quality of incoming cores causes difficulty in producing consistent results over time. In conventional manufacturing, managers remove as much variation as possible from the process. However, in remanufacturing, managers will need to deal with a certain level of variation. The variety does not, however, render lean tools inapplicable. For example, value stream mapping is a diagrammatic technique which illustrates all the activities required to bring a product from order to delivery. It aids understanding of the inherent complexities involved with the process and highlights waste. Similarly, a *current-state map* is a team effort that is carried out by the people who are involved in the process to characterize the current conditions. The *future-state map* introduces the opportunities for improvement recognized in the current-state map and represents a shared vision of a lean future state (Lean Enterprise Institute, 2003). Remanufacturing, strongly affected by variations in products and their quality, is much more complex than conventional manufacturing and, consequently, it is much more difficult to create a map. Depending on a component's condition, different operations are needed. The associated map might therefore be one of several variants available for each product family depending on the condition of cores/components.

Remanufactured products often add their own unique serial and part numbers. To ensure parts will not be mixed during the process, remanufacturers build *kits*. In these kits are individually separated components that are related to the same unit which are kept together in the same basket. Introducing the standardization of kits appears to be an advantageous opportunity for remanufacturers. Defining standards in terms of the work required to remanufacture as light, medium, and heavy also helps to reduce levels of uncertainty involved with the different conditions of products/components. Even though it is difficult to cover all aspects relating to existing variations, some sort of standardization can be achieved in the remanufacturing process. *All operations, no matter how creative or unpredictable, include a large amount of repetitive activities* (Petersson et al., 2010).

So, despite the variety encountered in remanufacturing, there is still an amount of repetitive work that presents opportunities for standardization. Even if not all possibilities can be covered, it still contributes to reducing variations in the system. When something is outside the standard, it provides information about the extremes of the process. Standards describe the best currently known way to perform an activity, which means that the workforce shares the knowledge that also contributes to learning. This is particularly important as remanufacturing relies heavily on human experiences compared with conventional manufacturing. According to Graupp and Wrona (2006), 5 to 10 percent of every work task embodies tackling "tricky parts" which require "know-how" skills gained through years of experience. Within the remanufacturing environment, this percentage might be substantially higher because of the high variability of the condition of cores. Indeed, it has been observed that the inspection process can only be carried out by skilled and experienced employees. In other words, identifying the condition of a component as "good enough" to be remanufactured needs years of experience.

The *Training Within Industry* (TWI) methods are a series of training programs developed during World War II allowing US companies to hire and train huge numbers of new employees to replace those who had gone to war. The TWI methods describe *standard work instructions* that should consist of not only major steps which are common-sense reminders of what is essential to do the work correctly, safely, and conscientiously, but also key points (illustrated by pictures or drawings) and reasons for them (Graupp and Wrona, 2006). They are called "key points" as they are essential pieces of information that make the work easy to do. Even though TWI methods describe standard work instructions as being effective during the teaching process, in the remanufacturing environment it was noticed that they might be successfully used in daily operations. Skills required in the remanufacturing environment are developed over time by employees, which shows the importance of taking part during the developmental processes of creating standard work instructions. Identifying the so-called "tricks" would perhaps be the most important and difficult task because employees very often don't want to share their knowledge and experiences. In addition, standardized work instructions in the remanufacturing environment often also cover acceptability criteria for the components, which are used to direct the operators on how to do the job. This can help in the decision-making process, especially for inexperienced employees or when new products are introduced to the facility.

Given the above, there is no doubt that the lean philosophy can be implemented within the remanufacturing environment; however, the question that inevitably arises is concerned with the improvement of that application. To be most effective, what is essential is a clear understanding of the underlying differences between lean remanufacturing and lean manufacturing.

Case Study: Lean Remanufacturing in Caterpillar

Caterpillar is both an OEM and successful remanufacturer with more than 30 years of expertise. The company as a whole recycles and remanufactures over 50,000 tons of used products per year (around 2.2 million end-of-life products). The operations are spread all over the world, amounting to 17 remanufacturing facilities that undertake remanufacture of medium- to heavy-duty machinery. As an OEM remanufacturer Caterpillar has access to the technical information on each and every component, and controls the aftermarket and intellectual property. The UK-based facility employs around 300 employees who are dedicated to remanufacturing. Within this facility, engines (mostly diesel), transmissions, gearboxes, oil pumps, water pumps, cylinder heads, cylinder packs, and individual engine components are remanufactured. Once a returned core arrives at the facility, it is disassembled so components are separated, losing their original identity. Usually, used products are very dirty, and so it is important to clean components to facilitate accurate assessment. Each element is inspected against strict engineering specifications to determine if it can be effectively salvaged. Accepted components are then reprocessed through advanced salvage techniques or directly reused. Those assessed as having satisfactory functionality move on to the reassembly area where new components are delivered as well. Here, products are reassembled, with each product having to pass a final inspection. If the required specification is matched, the product can be painted and shipped to the customer with an as-new warranty. The product is packaged in a way that clearly identifies it as remanufactured and not "new," where the term "new" describes newly manufactured using all virgin components (i.e. conventionally manufactured). The overview of the remanufacturing process is presented in Figure 16.2.

Lean manufacturing methods were first introduced into the company in 2005. Since then the principles and tools have been gradually implemented on a broader scale. Introducing value stream mapping was one of the first tasks undertaken by the lean team. It provided a good starting point for the company to describe and understand the inherent complexities involved with the remanufacturing process and highlighted wastes. The current-state map was the first map that was created within the facility. It showed all the processes, inventory, flow of information, etc., within the remanufacturing facility. As soon as the managers started to be more aware of the actual flow of material and information through the process, they saw numerous examples of waste and opportunities for improvements. As a result, the plant's layout was significantly changed.

Standard work instructions are of particular importance for the company during the visual inspection process. According to Errington and Childe (2013), the inspection step is crucial for

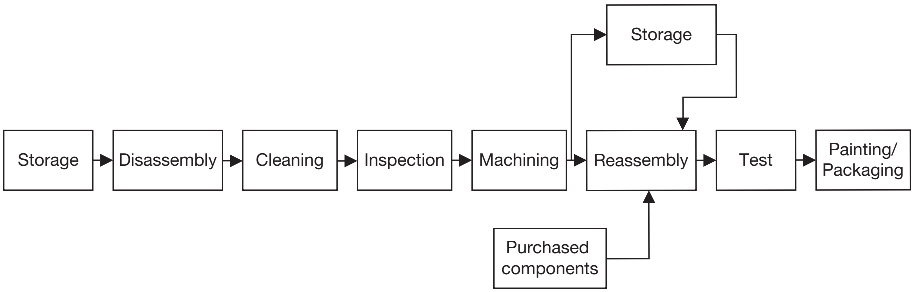

Figure 16.2 An overview of the remanufacturing process within Caterpillar

remanufacturing. The incorrect assessment of a core, or component, can cause unnecessary additional operational costs. As remanufacturing is strongly affected by variation in products and their quality, those tasked with assessment require precise knowledge of each variation. Standard work instructions are placed at the workstations and display sample components with given 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 assembly areas. 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 work instruction. This also serves to remind operators of the importance of quality.

Caterpillar also implemented visual management displays and controls within the facility's most critical areas. It provides clear information on how the most critical areas operate. The visual display boards introduced included section boards (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 10 most common defects are also presented on the section metrics boards. All of these visual displays 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. They make problems visible and allow all employees to quickly notice if a condition is in a normal or abnormal state. Employees have a meeting with managers every day, in which they discuss the previous day's production and the coming day's production, and disseminate any local or corporate information such as visits to the factory. There is 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, five whys, and histograms.

The interviews with managers also identified that Caterpillar has implemented standard work 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 *standardized work* for other processes such as machine maintenance and daily operator checks. This means they can give a standard to the operator but if additional salvage/activities are required they cannot always cover it in the documentation. For example, 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 production) or because the lead time for the new part is too long. In such a case, sometimes other similar used parts are adapted to make the part that is required.

To make sure that every machine is able to perform when required, Caterpillar has implemented *total productive maintenance* (TPM) for critical machines. Consequently, all employees, in a systematic way, are involved in maintenance routine, improvement projects, and simple repairs. To evaluate how effectively this equipment is used, the *overall equipment effectiveness* (OEE) is measured.

All these activities have improved the operations within Caterpillar by:

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

Despite the advantages gained from implementing lean manufacturing tools and principles, it was detected that individual processes are unstable due to the uncertain condition of cores. It is also difficult to determine cycle time—the time required to produce a part or complete a process, as timed by actual measurement—for each operation. Components have to go through different operations to meet the required specification. Some of them need more time to pass each step and in some cases some operations are omitted. Additionally, sometimes there is a need to wait for a new component, which causes a delay in a reassembly step, thereby causing waste in waiting and unnecessary transportation. The pull system within operations is difficult to apply because of the high variability and low repeatability of products.

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 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, making it difficult to keep workplaces clean.

Caterpillar has benefited widely from the application of lean within the remanufacturing environment. Following the idea that small, continuous improvements create long-lasting results, the company will implement a *kaizen* program, where, on an everyday basis, employees will be able to introduce improvements. In addition to the tangible benefits, employees will become more engaged with the wider culture and company as a whole.

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