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EXPLORING THE APPLICATION OF LEAN MANUFACTURING BEST PRACTICES IN THE REMANUFACTURING CONTEXT

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Sections of this thesis have been published as a conference contribution, book chapter, journal paper and presented at academic symposia. Therefore this thesis appears in the material outlined below:

Conference Papers/Conference Proceedings:

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Abstract

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. The remanufacturing process is rated as one of the most promising and cost-effective options 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). However, the process is more complex than traditional manufacturing and researchers have identified several difficulties that make process planning and control (PPC) more difficult in remanufacturing environments. For example, the degree of automation is usually lower and consequently, the amount of manual work is higher. Moreover remanufacturing facilities struggle not only with relatively high inventories of cores and finished product but also with inventories in between processes. Such issues impact negatively on remanufacturing performance measures like lead-time and costs. A system that will help to reduce cost, improve productivity and gain a competitive advantage is required. Previous research has confirmed that the combination of remanufacturing with lean manufacturing best practices appears to offer a good opportunity to increase process efficiencies within this type of industry.

Since Lean remanufacturing is still a novel field and there is a paucity of data and publications multiple case studies are used to gain insight into industrial activities and the performance of remanufacturing operations. Three case companies (two British and one Polish) operating within the remanufacturing industry were investigated. The study focuses on the automotive industry, which often demonstrates a greater understanding of lean thinking and practice, giving the opportunity to collect sufficient information to progress the research.

A key contribution of this research is the identification of lean practices that help manage the complexity in the remanufacturing processes thus improving general remanufacturing. This study confirmed that lean practices such as standardisation, Kanban, Cross-functional workforce, production analysis board, 5S, visual management, cellular manufacturing and TPM help manage the negative effect of the inherent complexities of the remanufacturing process. An Opportunities Matrix *has been developed so that the findings can be more easily used by industry. Moreover, factors that limit the application of Lean practices within remanufacturing were also discussed. This research confirmed that the complexities of the remanufacturing process such as stochastic routings for material for remanufacturing operations, uncertainty in materials recovered from returned items, highly variable processing time and the complication of material matching restrictions limit the application of FIFO, standardised work instructions, Kanban, cellular manufacturing. A Threats Matrix has also been developed to visualise the research findings. Both academic and industry benefit from this research. Remanufacturing companies can use this study to choose suitable lean practices for addressing challenges that are facing. Further research should be focused on the particular lean tools that are identified in this research as difficult or impossible to implement in remanufacturing.*

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Last but not least, I am grateful to my Mom, my Dad, my Brother and my Fiancé. Without their care and support, the words in this thesis would have never reached print. For this, I am eternally grateful.

Content

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List of acronyms

5S	Five S
5W1H	When, Where, Who, What, Why and How
8D	8 critical steps for solving problems
CE	Circular economy
FIFO	First In, First Out
KPI	Key Performance Indicators
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
Pcs	Pieces
PhD	Doctor of Philosophy
POM	Production and Operations Management
PPC	Pieces
SMED	Single Minute Exchange of Die
SQDC	Safety, Safety, Quality, Delivery and Cost
TPM	Total Productive Maintenance
VSM	Value Stream Mapping

1 Introduction

Continued strains on the planet's resources, including limited sites for product disposal and the introduction of new environmental legislation, have resulted in a growing interest in the concept of the circular economy (CE). It is considered as a solution for ‘harmonizing ambitions for economic growth and environmental protection’(Lieder and Rashid, 2016a). The circular economy promotes material and product recovery options like recycling, reuse, remanufacturing and refurbishment. This chapter introduces the research aim, objectives and research questions.

1.1 Research aim and scope

The motivation for this research is borne out of a desire to enhance remanufacturing productivity. Thus this work aims to explore the application of Lean in the remanufacturing context. The major objective of this work is to provide a detailed understanding of the relationship between lean efforts and the complicating characteristics of the remanufacturing process identified in the existing literature.

Previous researchers identified several characteristics that complicate production planning and control (PPC) and have not been addressed. This research is directed towards such challenges and how they interact with Lean tools and principles.

Remanufacturing is carried out across a wide range of industries ranging from textiles, construction, and electronics. It was reported that the automotive sector is the largest remanufacturing sector, which accounts for about two-thirds of global remanufacturing activities (‘Remanufactured goods: An overview of the U.S. and global industries, markets, and trade’, 2013). Thus access to data from the automotive sector is likely to be more accessible. Moreover, the results will significantly impact the remanufacturing environment because a great number of companies are involved. For these reasons, this research focuses on lean operations within the remanufacturing process of automotive remanufacturers.

1.2 Rationale

To make sure that remanufactured products can compete with brand new products, remanufacturers have to provide customers with good quality products at a competitive price and time that the customer wants them. Companies implement Lean to reduce cost and increase productivity and thus gain a competitive advantage. It was identified in the existing literature that some of the lean tools are difficult to implement within the remanufacturing context because the remanufacturing process is much more complicated and faces challenges that don't exist within conventional manufacturing (Sundin & Ostlin, 2005). For example, some of the challenges that complicate many activities within the remanufacturing context were identified by previous researchers as:

- Challenge 1: *Disassembly of returned products*
- Challenge 2: *Complication of material matching restrictions*
- Challenge 3: *Uncertain timing and the quantity of returns*
- Challenge 4: *Need to balance returns with demand*
- Challenge 5: *The requirement for a reverse logistics network*
- Challenge 6: *Uncertainty in materials recovered from returned items*
- Challenge 7: *Stochastic routings for materials*
- Challenge 8: *Highly Variable processing times*

More will be said about each of these in later chapters of the thesis. Automotive remanufacturers have been chosen because this sector is more mature and often demonstrates a greater understanding of lean principles than others. Hence there is an opportunity to get sufficient information to progress the research.

Even though it is relatively little in the academic literature relating to the application of lean to remanufacturing, practitioner expansion seems to be more. Some companies, particularly OEM's, are obliged to introduce lean within their facilities according to corporate policies and procedures.

1.3 Research Questions

1. **How does the application of lean practices reduce the impact of the complexity of production planning and control in the remanufacturing processes?**

Although previous research has identified challenges that remanufacturing companies are facing, many issues have not been resolved. For example, Lundmark, Sundin, & Björkman (2009) claim that it is important for future research to investigate how the uncertainty and complexity within the remanufacturing system can be tackled and how to meet the remanufacturing challenges detailed in chapter 2.2.3. The study done by Kurilova-Palisaitiene, et al. (2018) attempts to start closing that gap in the literature. They have developed suggestions to tackle remanufacturing challenges with the aim of shorter lead time. Potential improvements have been identified as a result of focus group interviews. Kurilova-Palisaitiene et al. (2018) have highlighted that the discussed lean tools should be tested and verified at remanufacturing companies. Given the success of Lean in other industries it is appropriate to explore whether by adopting a lean approach, remanufacturers could overcome the negative effects of several of the previously identified remanufacturing challenges, thus making PPC activities in remanufacturing environments simpler to execute. According to the suggestions done by Kurilova-Palisaitiene et al. (2018), our research will observe and verify practices used in case companies who are already applying Lean methods in remanufacturing processes.

2. **How does the complexity of the remanufacturing process limit the application of lean practices?**

The factors that limit the application of lean tools within conventional manufacturing has been widely described in the existing literature. However limited research is available regarding the limitation of applying lean within the remanufacturing context. Guide (2000) describes the major challenges that differentiate the remanufacturing process from conventional manufacturing (see chapter 2.2.3). Thus this research will focus mainly on these complexities and how they limit the application of lean within the remanufacturing context.

1.4 Novelty

Guide (2000) and Junior and Filho, (2011) have detailed the challenges that remanufacturing companies are facing. Lean remanufacturing has become a new research direction to improve the performance of remanufacturing (Kucner, (2008); Pawlik, Ijomah and Corney, (2016); Kurilova-Palisaitiene, Sundin and Poksinska, (2018)). Moreover (Matsumoto *et al.*, 2016) has indicated that because operations management is more complex than conventional manufacturing, research on forecasting, product scheduling, capacity planning, production planning and inventory management are required to support the development of efficient and effective remanufacturing systems. Using this as a foundation the research reported here shows how remanufacturers can overcome existing challenges using the application of particular lean tools and principles. Moreover, previous research confirmed that the application of lean within remanufacturing is challenged by the remanufacturing constraints identified by (Guide, 2000). Previous research has not identified which lean practices are affected and why. This knowledge is necessary to improve that application.

1.5 Thesis Structure

Table 1-1 presents the thesis structure.

Table 1-1 Thesis Structure

Chapter 1: Introduction	This chapter introduces the research aim, objectives and research questions.
Chapter 2: Literature Review	This chapter provides a comprehensive review of published research related to remanufacturing, lean manufacturing, and lean remanufacturing.
Chapter 3: Field Work: Pilot Case Study	This chapter aims to examine lean remanufacturing practices within the industry to identify needs for future research as the existing literature is very limited.
Chapter 4: Research Design	In this chapter, the research paradigm is presented and its components (ontology and epistemology) are further discussed. Moreover, the methodology chosen for this research is identified, explained and justified. Appropriate methods to collect and analyze data are then identified to ensure that the research follows a strict and rigorous procedure.
Chapter 5: Field Work: Case Study Research	The chapter presents the findings from each case company and the discussion of the relevant data. Key findings for each case company will be highlighted. Moreover, the data from all the case study companies were compared and contrasted to build up a bigger picture.
Chapter 6: Field Work: Validation	In this chapter, the results from the case studies were validated through a fifth case company that was until then uninvolved in the research
Chapter 7: Discussion and Conclusions	This chapter seeks to triangulate the results from the three cases, into a more generalizable set of findings. Moreover, it also presents the conclusion of this research study to make a clear contribution to remanufacture and provides recommendations for future research

2 Literature Review

This chapter provides a comprehensive review of published research related to remanufacturing, lean manufacturing, and lean remanufacturing.

2.1 Literature Review Method

Undertaking a review of the literature is a significant part of any research study because it establishes both the state-of-the-art and also the scope of the work (Tranfield, Denyer and Smart, 2003). The traditional literature review aims to collect and synthesise primary findings from research studies performed on a particular topic. The literature review is a summary of studies that presents an overview of the state of relevant knowledge in that area (Rozas and Klein, 2010). In the first stage of searching for papers, the search was restricted to publications containing the phase 'Remanufacturing' and 'Lean Manufacturing'. The initial search yielded many articles related to lean manufacturing and remanufacturing, many of which did not pertain to the research interest. In order to restrict the search to articles relevant to the scope of this study, documents containing the phrase 'Lean Remanufacturing', 'Remanufacturing Challenges', and 'Lean Manufacturing Tools' in the title, abstract and keywords of published papers were selected. Cross-referencing and recommendations from supervisors and colleagues were considered to form the final selection of papers for literature analysis. The databases of ISI Web of Knowledge, ProQuest, Science Direct, Emerald, and Google Scholar were used to gather access to relevant articles. The number of selected papers is presented in Table 2-1.

Table 2-1Numberof papers returned from each database

Database	Keyword (in title, abstract, keywords)	Number of papers
Google Scholar	**Stage one: Remanufacturing**	**5 130**
	Stage two: Lean and Remanufacturing	38
	Stage two: Remanufacturing and Challenges	59
	Stage one: Lean Manufacturing	**8 420**
	Stage two: Lean Manufacturing and Tools	325
Emerald	**Stage one: Remanufacturing**	**953**
	Stage two: Lean and Remanufacturing	0
	Stage two: Remanufacturing and Challenges	12
	Stage one: Lean Manufacturing	**632**
	Stage two: Lean Manufacturing and Tools	159
Science Direct	**Stage one: Remanufacturing**	**1 189**
	Stage two: Lean and Remanufacturing	7
	Stage two: Remanufacturing and Challenges	109
	Stage one: Lean Manufacturing	**902**
	Stage two: Lean Manufacturing and Tools	226
ProQuest	**Stage one: Remanufacturing**	**3 418**
	Stage two: Lean and Remanufacturing	12
	Stage two: Remanufacturing and Challenges	21
	Stage one: Lean Manufacturing	**2774**
	Stage two: Lean Manufacturing and Tools	111
ISI Web of Knowledge	**Stage one: Remanufacturing**	**1 750**
	Stage two: Lean and Remanufacturing	7
	Stage two: Remanufacturing and Challenges	13
	Stage one: Lean Manufacturing	**947**
	Stage two: Lean Manufacturing and Tools	61

2.2 Introduction to Remanufacturing

Continued strain on the planet's resources, including limited sites for product disposal and the introduction of new environmental legislation have resulted in a growing interest in the idea of a circular economy (CE) as a way of 'harmonizing ambitions for economic growth and environmental protection'(Lieder and Rashid, 2016b). A CE maximises material and product recovery options to reduce environmental impact and resource consumption. However, to be sustainable a CE must also be economically viable with productive and profitable commercial activities. One of the most promising and cost-effective options for establishing low-carbon manufacture and a 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).

2.2.1 Material and Product Recovery Opportunities

To understand why remanufacturing is one of the most promising and cost-effective product recovery options it is important to explain what other existing opportunities are available. There is some confusion in the literature around the terminology used to describe these different processes. Different terms are used by different industrial sectors and even different organizations (Errington and Childe, 2013).

Besides remanufacturing, existing literature highlights other product recovery options:

Repair: Repair means a '*returning a faulty or broken product or component back to a usable state'* (Ijomah, 2002). This may involve the use of remanufactured or brand new parts. The quality of repaired items is lower than the quality of a new one as the effort is limited to the specified fault. Therefore the warranty applies only to the components that have been replaced or repaired (Ijomah *et al.*, 2005).

Materials Recycling: It is a well-known strategy which recovers some or all of the materials from returned items however the product does not retain its functionality and loses its original form. Unlike in remanufacturing or reconditioning, recycling is being done at the material level, therefore a greater amount of energy and effort is required.

Recondition: This practice is particularly common in the automotive sector where vehicles after several years of use are reconditioned and sold to a different market (for example developing countries where the majority cannot afford to buy a brand new product). Reconditioning requires more effort than repair but less than remanufacturing (Figure 2-1).

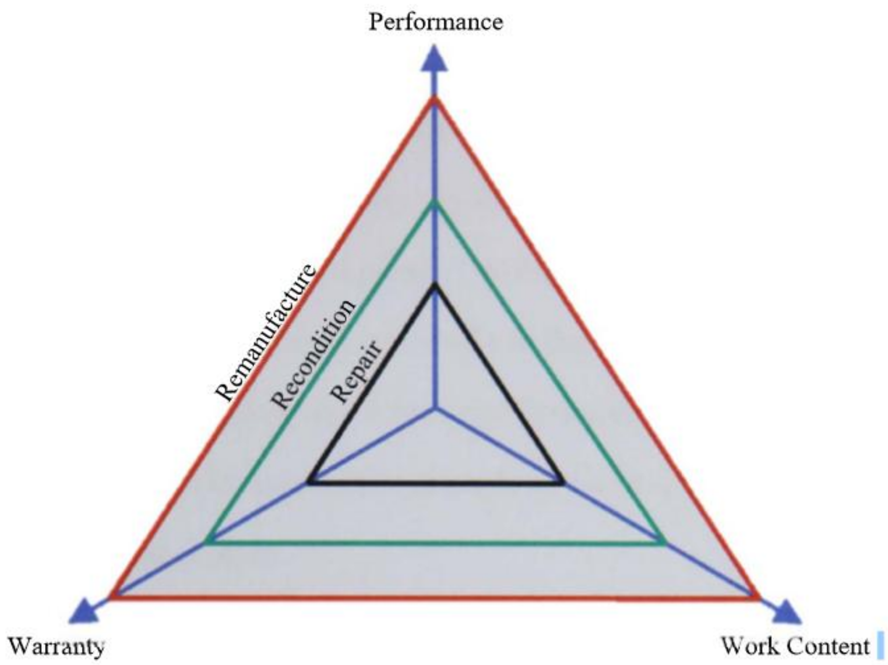

Figure 2-1 Comparison of repair, recondition and remanufacture (Ijomah, 2002)

Repurpose: Repurpose is *"utilization of a product or its components in a role that it was not originally designed to perform*" (British Standards Institute, 2009). Discarded products or their parts are used for a purpose other than was originally intended.

2.2.2 Remanufacturing Process

Usually, the remanufacturing process starts with the initial cleaning of used products (cores). Generally, the cores that return from the field are dirty, which often impedes assessing their condition (Ijomah, 2002). Upon receipt, cores are disassembled so that each component is separated. The components are then individually cleaned which helps investigate their condition. Depending on the quality of the components, the value of the components (cost of remanufacturing compared to the cost of a new component), and safety restrictions; the parts are remanufactured or rejected from the process. 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.). When all required components are collected (including remanufactured parts and new components), assembly kits can be organised and the product reassembled. After this, the entire product passes a final test to ensure that quality is at least equal to a newly manufactured, equivalent product (Figure 2-2) (Ijomah, 2002). In some cases, products can be upgraded to the latest version (Ijomah, 2002)

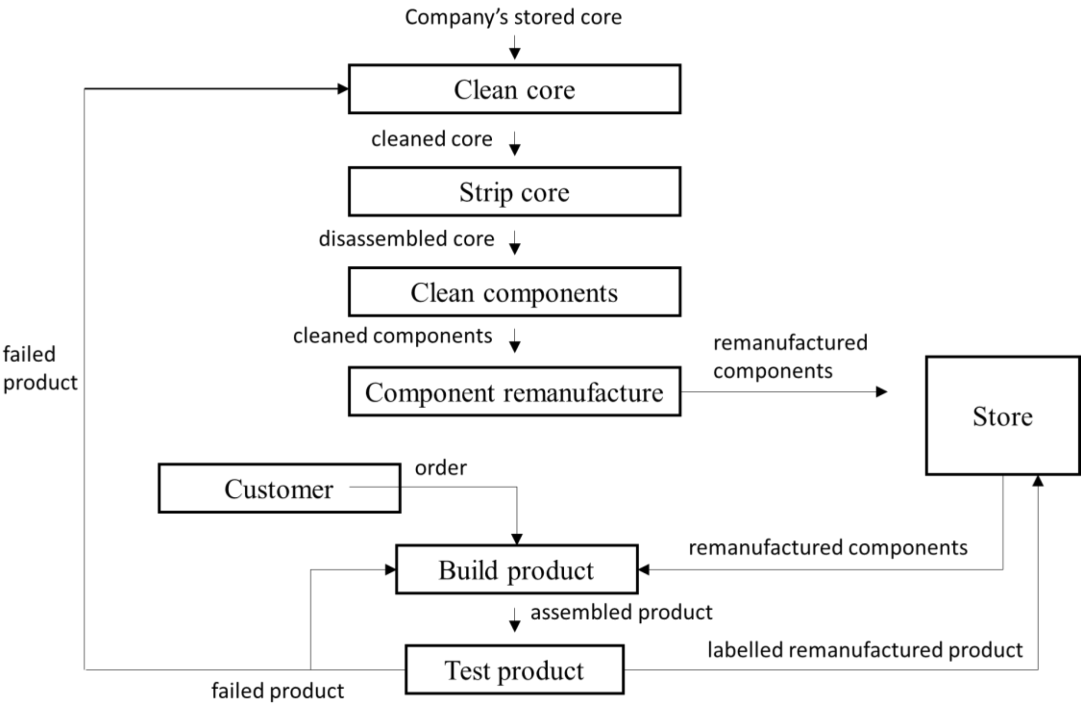

Figure 2-2 Generic remanufacturing process chart (Ijomah, 2002)

CLEAN

Usually used products, which are taken from the market, are dirty. That makes an evaluation of cores difficult therefore the initial cleaning is required. The aim of this operation is to assess the specific part number and general condition of cores. After cleaning it is easier to see any defects or missing parts, therefore, cores that are in a very bad condition might be removed from the process at this point. This will help to eliminate the further cost of unnecessary storing and disassembly.

STRIP CORE

In regards to bringing a used product to as good as new condition, it needs to be disassembled. Some joining to be loosened can cause parts damage. However, according to Steinhilper, (1998) majority can be taken apart non-destructively.

INSPECTION

Inspection is a very important step in the remanufacturing process and requires skilled employees to determine the quality of parts. During this operation, workers use a minimum of supporting information/equipment (mainly a visual inspection is used).

COMPONENT REMANUFACTURE

Component remanufacture (a major part of remanufacturing) is a process to restore a component or subassembly which includes: machining, material deposition, heat treatment and welding. *The components are usually restored to within OEM specifications. However, this may not be essential as long as the product can be proven to be functionally as good as new, which is the overarching requirement* (Parkinson and Thompson, 2003).

BUILD PRODUCT

Cleaned and inspected parts are assembled together to make a like-new condition product. General assembly tools and techniques are used. However, full automation is still difficult to apply as remanufacturers have to deal with a variety of product type and high uncertainty is inherent in remanufacturing. Thus the process is very labour intensive.

TEST PRODUCT

The final stage in the remanufacturing process is the testing of remanufactured products. This test is similar to the one performed for newly manufactured products. High-tech machinery is used in this stage, compared to the other operations of remanufacturing. If the test is failed the unit has to be sent back to disassembly for reprocessing.

There are several possible shop structures available for remanufacturing facilities that are used depending on the type of products remanufactured. The shop floor can be organised in different ways depending on repetitive-type work such as cell phones, or a job-type structure like ship remanufacturing (Guide and Srivastava, 1998). Guide & Srivastava (1998) also describe the structure that can be seen in many facilities that remanufacture commercial products, such as photocopiers, automotive parts, and inkjet printers. They noticed that the remanufacturing system is divided into three highly dependent subsystems (Figure 2-3):

- **disassembly shop** – where used products are disassembled after arriving at the facility
- **remanufacturing shop** – where the components are brought back to an as-good-as-new condition
- **reassembly shop** – where the final product is reassembled.

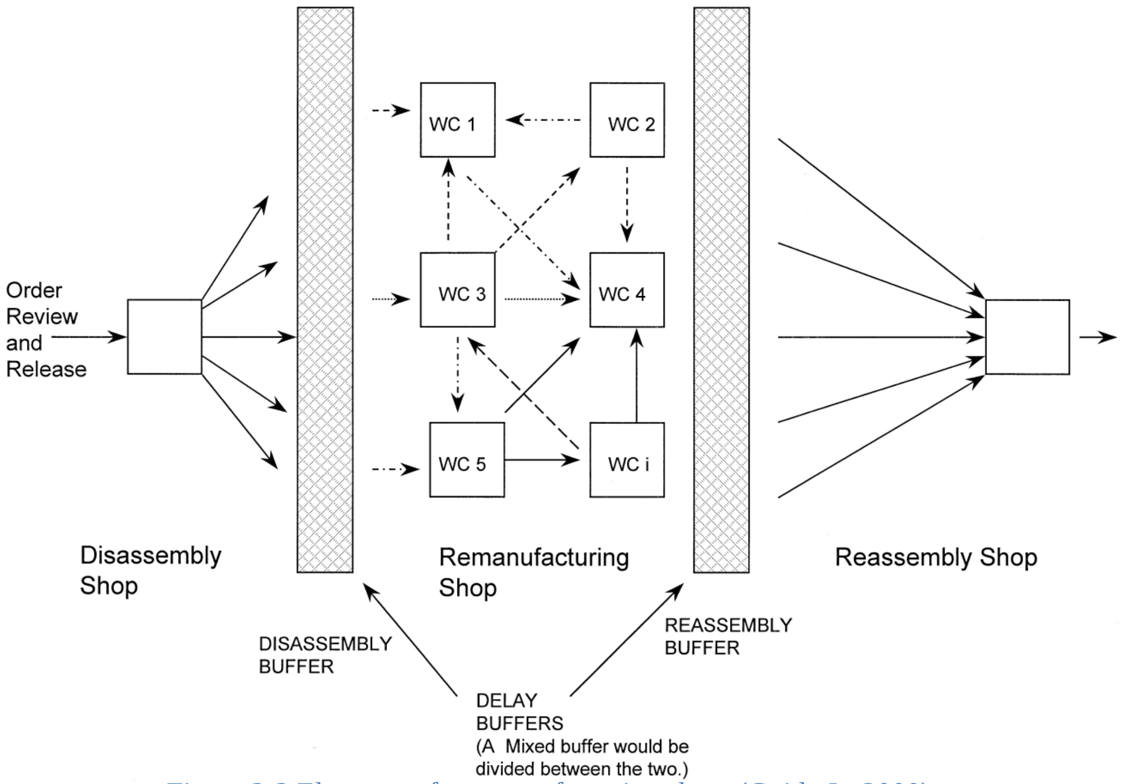

Figure 2-3 Elements of a remanufacturing shop. (Guide Jr, 2000)

Remanufacturing facilities struggle not only with relatively high inventories of cores and finished product but also with inventories in between processes. There are three possible locations for them identified by (Guide and Srivastava, 1998).

1. At, or immediately after the disassembly, often referred to as a disassembly buffer.
2. Just prior to, or at the reassembly operation, often referred to as a reassembly buffer.
3. Divided between disassembly and reassembly buffer, called a mixed buffer.

However, high inventory is not the only challenge that exists within the remanufacturing environment, as we explore in the following section.

2.2.3 Remanufacturing Challenges

The remanufacturing process differs from conventional manufacturing, thus remanufacturers face different challenges from those experienced by conventional manufacturers. Casper and Sundin, (2018) confirmed that automotive remanufacturers face a wide range of challenges and it is important for further research to better understand such challenges and address them to stay competitive. This is particularly important because, as Chakraborty, Mondal and Mukherjee, (2019) highlighted, almost 46% of the remanufactured products are automotive products and components. Currently, OEM's have programs that include remanufactured parts, due to rising production costs (Casper and Sundin, 2018).

Few researchers distinguish the major challenges that influence and complicate PPC activities within the remanufacturing industry (Guide Jr (2000), Lundmark, Sundin and Björkman, (2009); Junior and Filho, (2011); Kurilova-Palisaitiene, Sundin and Poksinska, (2018)).

Disassembly of returned products

The returned product has to be disassembled first, before going to the next remanufacturing operation and the result of this stage impacts many activities like purchasing new components, scheduling and resource planning. Difficulties can arise because the products have not been designed with disassembly in mind, and 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 of existing automated techniques that can be used during disassembly, this also makes this task very labour-intensive with highly variable processing times. After the disassembly, the quality of components can be identified.

The complication of material matching restrictions

The complication of material matching requirements means that because products have their unique serial and part numbers, often 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 materials management. Very often remanufacturers keep all components in kits. In these kits are individually separated components that are related to the same unit which is kept together in the same basket.

Uncertain timing and the quantity of returns

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 amount and time returned cores cannot be controlled by remanufacturers forces them to keep a higher level of inventory against variability in supply and demand.

Need to balance returns with demand

To avoid excessive inventory (that generates cost) and at the same time to be able to meet customer expectations for remanufactured products, remanufacturers have to balance the returns and demand rate. It requires extra effort that includes not only core acquisition (that includes identifying the potential source for cores, establishing preferences etc.) but also coordination in purchased replacement parts that depend on expected volume and condition of cores. Moreover, all of the production decisions in regards to resource planning depend also on core acquisition and timing.

The requirement for reverse logistics network

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

Uncertainties in quality incoming cores causes:

Uncertainty in materials recovered from returned items

The remanufacturers have to acquire the replacement for parts that cannot be reused from cores. It seems to be much more complicated when it is difficult to predict the rate of material recovery before the product is disassembled. Very often two identical returned items may contain very different sets of parts that are or can be returned to an expected condition.

Stochastic routings for materials

It is a consequence of the varying condition of cores. The same components taken from different products might require different processes to be recovered

Highly Variable processing times

Equal parts might require a different degree of treatment for each remanufacturing operation.

Providing high-quality products at a low price that will be delivered when the customer wants can assure that remanufactured products can compete with brand new products. A system that will help to reduce cost, improve productivity and gain a competitive advantage is required.

2.2.4 Type of Remanufacturers

There are three main types of remanufacturers highlighted in the existing literature:

- OEM Remanufacturers
- Contract Remanufacturers
- Independent Remanufacturers

Each of them will be briefly presented in the following sections:

- **OEM Remanufacturers** design**,** produce and sell both new and remanufactured versions of its products. The majority of OEMs remanufacture their products in separate manufacturing areas or sites. Nevertheless, Volvo shows that the integration of remanufacturing into the manufacturing line can be successful as well (Mähl and Östlin, 2007).
- **Contract Remanufacturer** – is remanufacturing under license for the company/person that is the owner of this product, often with their technical support.
- **Independent Remanufacturer –** is buying and remanufacturing other people goods without license and support to resell them on the aftermarket. (Lund, 1983)

2.3 Introduction to Lean Management

Lean manufacturing is considered as a very attractive way to achieve competitive advantage in manufacturing. It is about creating the most value for the customer while minimizing resources, and time, through the elimination of any interruptions in a flow of material and information. Any activities that consume resources without creating value for the customer are referred to as a waste (Muda). Lean is based on continuous improvement.

Womack & Jones (1996) in their book *Lean Thinking* defined Lean a five-step process that creates a Lean organization (Figure 2-4):

1. Understanding the ***value*** from the customer's point of view;
2. Identify the ***value stream;***
3. Make value ***flow*** continuously through the remaining value-added steps;
4. Introduce ***pull*** between all steps where continuous flow is possible;
5. Seek ***perfection*** through continuous improvement.

Figure 2-4 Lean Principles https://www.lean.org/WhatsLean/Principles.cfm

- **Value**

'The critical starting point for the lean thinking is value. Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time.' (Womack and Jones, 1996, p. 16).

The value is defined from the customer's point of view and represents what customers are willing to pay (Bicheno and Holweg, 2009). Activities that do not contribute to the value are a waste.

Waste (MUDA)

Waste (known by its Japanese name *Muda*), can be expressed as anything that adds costs without adding value. Bicheno & Holweg (2009) states that waste reduction was a key element from the beginning of Lean, and is still a fundamental aspect. Existing literature identifies eight waste types, which is inherited in most businesses:

- **Overproduction** – means to produce more than what the customer is asking for (what is required by the marketplace). Ohno believed that this waste is the most serious as generates another one.
- **Waiting (time on hand)** – represents a time when employees are watching an automated machine; waiting for the next processing step, part, tool, supply; or having no work because of equipment downtime, capacity bottlenecks, delays.
- **Unnecessary transport** – from a customer point of view any movement of material is a waste, customers do not want to pay to

have materials, parts or finished goods moved into or out of a warehouse or between processes. Moreover, transportation influences the likelihood of product's damage.

- **Over-processing or incorrect processing** – involves unnecessary steps or inappropriate processing (due to inadequate tools and design) that provide higher quality products that are required.
- **Excess Inventory** – refers to raw material, WIP, or finished goods that tend to increase lead-time, transportation and storage cost. In addition might cause damage to products, obsolesce and delays. Moreover, extra inventory prevents rapid identification of problems such as late deliveries from suppliers, defects, long setup time, equipment downtime etc.
- **Unnecessary movement –** refers to any unnecessary motions (also walking) that employees have to perform at work such as reaching for, looking for tools, parts etc. It applies to both human and layout (poor workplace arrangements).
- **Defects –** both internal failure (delay, rework, scrap), and external failure (repairs, warranties, and the possibility of losing customers) cost money. In addition, they might cost even more when they remain undetected as time goes on.
- **Unused employee creativity –** refers to not listening and not engaging employees and thinking that only managers can have ideas worth following. (Liker, 2004; Bicheno and Holweg, 2009)

Value Stream

The value stream is the set of all the specific actions required to bring a specific product through the three critical management tasks of any business: the problem-solving task running from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation task proceeding from raw materials to a finished product in hands of the customer (Jones, 1996, p. 19).

All the activities that are performed from concept to launch into the hands of the customers should be identified for each product or in some cases for each product family (groups of products requiring similar processes etc.). Identifying the entire value stream exposes enormous amounts of waste.

Flow

'Once a value has been precisely specified, the value stream for a specific product fully mapped by the lean enterprise, and obviously wasteful steps eliminated, it's time for the next step in lean thinking – a truly breathtaking one: Make the remaining, value-creating step flow.

Flow is a concept which defines the status of material movement from process to process and is a fundamental piece of lean. Ohno claimed that one-piece flow, also called 'continuous flow' is the ideal however extremely difficult to achieve and not always practical. The products will be produced with the highest efficiency when moving continuously from process to process, travelling on the shortest distance with minimal waiting time in between the processing steps.

Connecting two or more processes into a continuous flow helps to reduce WIP and show the problems that otherwise might stay hidden in an inventory (Liker and Meier, 2005).

- **Pull**

'Pull in simplest term means that no one upstream should produce a good or service until the customer downstream asks for it' (Jones, 1996, p. 67)

As flow is introduced, the next step is to synchronise the already balanced production operations to the rate of customer demand. Pull dictates when the material is moved. Kanban is a mechanism that is typically used to control the pull system.

- **Perfection**

"As organizations begin to accurately specify a value, identify the entire value stream, make the value-creating steps for specific products flow continuously, and let customers pull value from the enterprise, something very odd begins to happen…suddenly perfection doesn't seem like a crazy idea" (Jones, 1996).

Perfection represents the culture of continuous improvement that is essential for lean to succeed. Continuous improvement is a fundamental part of lean management.

2.3.1 Common Lean Concepts and Tools

The entire range of Lean tools was developed for the practical application of lean. It is important to highlight that Lean should not be perceived as a set of tools that have to be applied in a particular order. Lean provides tools which need to be chosen according to the goals that the company is trying to achieve or the problems it is trying to solve. (Jones, 1996; Liker and Meier, 2005; Bicheno and Holweg, 2009). Because such tools are already described in detail in a wealth of literature, we do not go into great details of describing each of the approaches here. For this reason, the reader is directed to such works as (Bicheno and Holweg, 2009) or Lean Enterprise Institute (2014), for example.

Kanban – A signalling device, in a pull system, that gives permission and instruction for the production or transportation items. It can be represented as a space on the floor if the two operations are near to each other. Kanban can be also a card, return of an empty rack, or an electronic signal. It should contain maximum and minimum limits for the inventory, part name, part number, quantity, supplier and customer locations etc. There are two forms of kanban:

- transportation kanban – it gives permission to material handlers to move products.
- production kanban – it gives the authorization to make products. (Lean Enterprise Institute, 2014)

Standardised Work Instructions – is used to direct operators and to standardise operations. According to Damiani (2016), standard procedures allow maintaining the quality of the product through the whole process. *The first car is as good as the 500th or 500000th car.* He also highlighted that it is important to involve employees while developing those procedures so workers can feel like owners of those processes. In result, they will be willing to follow them.

Visual Management – provide clear information about how the factory is operating. Visual control and visual displays create visual management. It allows people to quickly identify how the factory is running. Problems are visible and everyone can see if a condition is in the normal or abnormal state (Elbert, 2018).

Five S (5S) – The 5S method can be an example of visual management. The aim of using 5S is to reduce waste, variation and to improve productivity through maintaining an orderly workplace and using visual cues.

- **S**eiri – **S**ort – the first step is to decide (using sorting criteria) what tools are needed in the workplace. Unused tools, resources etc. needs to be thrown out whereas less frequently used should be kept in cupboards or a storeroom. Hence it makes easier to work, easier for operators to move, and easier for material to flow.
- **S**eiton – **S**implify – Everything remaining needs to be located in a sensible place and labelled as belonging to that area. It is important to place such items in places where the ergonomic principles to minimise stretching and bending have been considered.
- **S**eiso – **S**can – is concentrated on physical tidiness and 'visual scanning' to search for anything out of place and to amend it straight away.
- **S**eiketsu – **S**tandardise –Developing standards for the first 3S is important to make sure that employees will not revert to old habits.
- **S**hitsuke – **S**ustain – is all about participation and improvement to make sure that the other 5S activities become a habit. It requires conducting formal and regular audits. (Feld, 2000; Bicheno and Holweg, 2009).

Production Analysis Board – Production Analysis Boards are located near the production line and they present the actual performance of a process compared with planned performance. If the plan hasn't been achieved, the team leader has to write down the reason. It is a problem-identification and problem-solving tool. An example of the production analysis board is presented in Figure 2-5 (Lean, Enterprise and Institute, 2003).

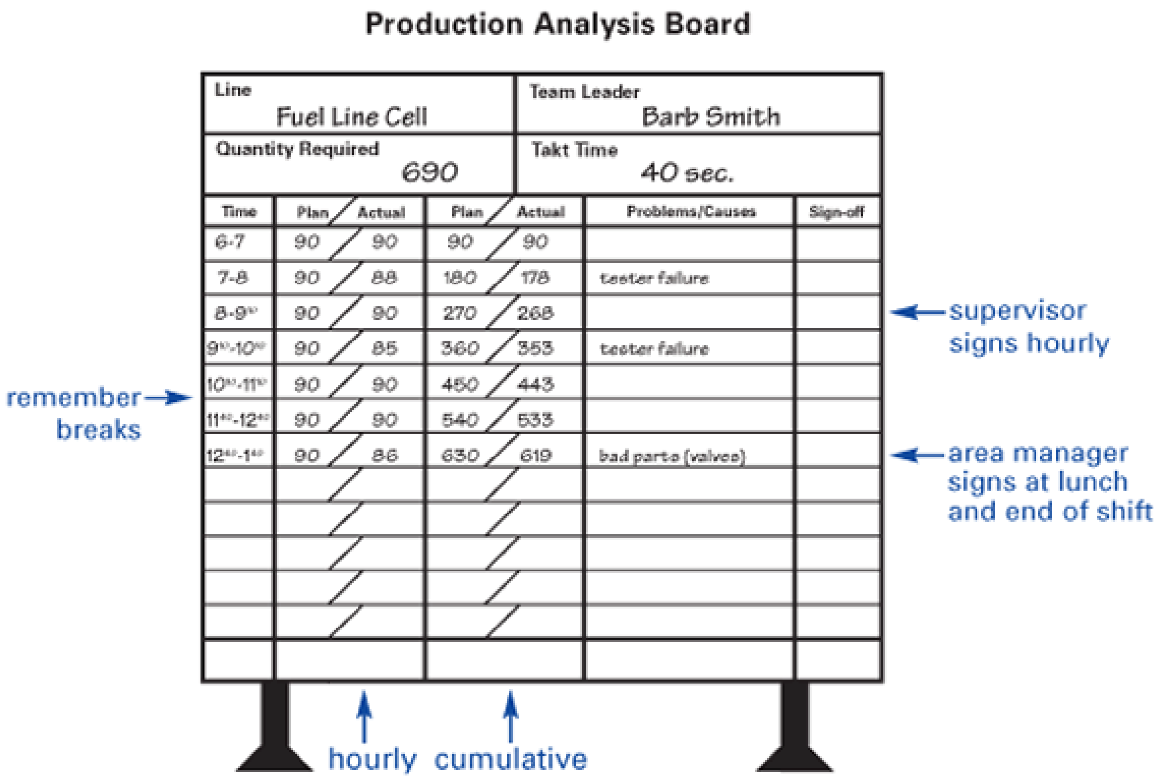

Figure 2-5 An example of production analysis board. Source: https://www.lean.org/lexicon/production-analysis-board

Total Productive Maintenance – was developed as an approach to plant maintenance to maximise the utility of resources. It combines productive maintenance procedures with quality control and employee involvement to achieve zero accidents, zero defects, and zero breakdowns (Tajiri and Gotoh, 1992).

Value Stream Mapping (VSM) – A diagram that illustrates every step required to bring a product from order to delivery. It includes both the material and information flow. VSM is used for analyzing the current state and designing a future state that represents the concept of what the company is trying to achieve. (Liker and Meier, 2005; Lean Enterprise Institute, 2014).

Poka-Yoke – People are making mistakes, but that is not the same as a defect. A defect is a result of error and happens after an error occurs. '*A Poka-yoke system possesses two functions: it can carry out 100 per cent inspections and, if abnormalities occur, it can carry out immediate feedback and action'* (Shingo, 1986). Poka-yoke defines simple and not expensive devices designed to catch an error before it causes the defect. The aim of adopting this tool is to prevent defects at the source and not allow them to pass on a defective component to the next operation (Feld, 2000).

First In, First Out (FIFO) – The principle and practice that ensures the first part that enters the process (or storage location) is also the first part to exit. Pull system require FIFO. An example of a FIFO line is presented in Figure 2-6 (Lean Enterprise Institute, 2014).

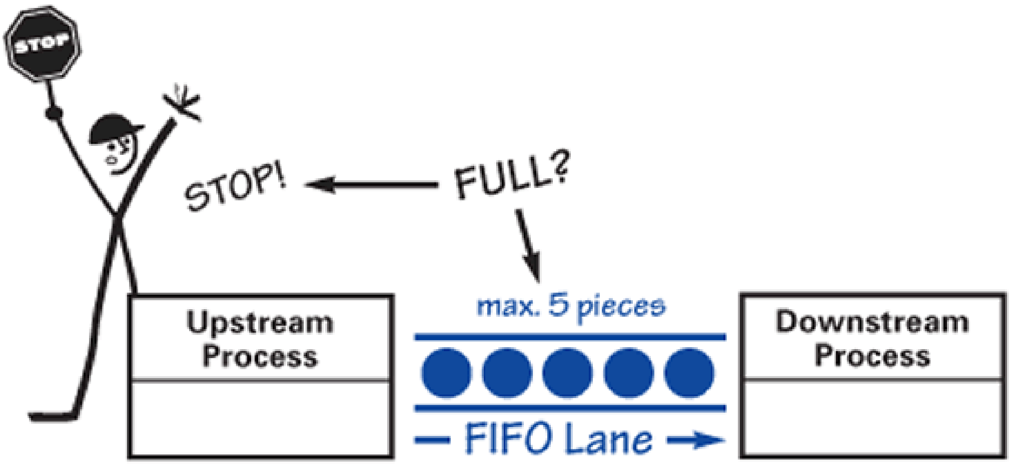

Figure 2-6 An example of FIFO line. Source: https://www.lean.org/lexicon_images/207.gif

Five Why – it is a practice of asking ‘why’ questions persistently to identify the root causes of the problem that was an encounter.

2.4 Lean Remanufacturing: The Application of Lean within Remanufacturing Environment

Lean has its roots in the automotive industry although Womack and Jones extended it beyond that industry. Existing literature also shows examples of the successful application within different industries and sectors like the service industry, healthcare and aerospace industry. The application of the lean manufacturing approach within a remanufacturing context – termed “Lean Remanufacturing” – has only recently gained the attention of researchers and practitioners (Kucner (2008), Pawlik, Ijomah, & Corney (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). Kucner (2008) highlighted several examples of successful applications of lean tools and practices within the naval ship repair industry. Compared to conventional manufacturing, there is relatively little in the academic literature relating to the application of lean to remanufacturing. Vasanthakumar, Vinodh and Ramesh, (2016) suggested adopting Lean remanufacturing to improve the performance of the remanufacturing assembly system. The first reported study of lean remanufacturing was presented by Amezquita & Bras (1996) which focuses on an independent automotive remanufacturer of an automobile clutch. This research compared a remanufacturing process that contains craft and mass production practices, with lean remanufacturing practices. A major benefit that was noticed was the elimination of the non-value-added operations, which result in enormous cost savings. Kucner (2008) claims that lean production tools and techniques can be applied to remanufacturing, however, there is not simply one best way but specific solutions must be tailored to particular remanufacturing context. He examined 4 types of the remanufacturing processes, ranging from high product variability to low product variability and in each of these cases the implementation of lean methods significantly improved performance, particularly in developing internal process stability, build–in quality and just in time production. Fargher Jr (2007) and Pawlik, Ijomah, & Corney (2013a) also confirmed that the application of lean manufacturing within remanufacturing operations can bring significant benefits including a reduction in lead-time, reduced work in process, improved on-time shipments, increased utilization of floor space, improved quality, increased production control (Elzbieta Pawlik, Ijomah and Corney, 2013c). Sundin (2006) used The Rapid Plant Assessment tool to investigate 5 case companies (from different remanufacturing sectors). The result of this study shows that the investigated remanufacturer performs well in 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 and Material Movements’, and Inventory and WIP Level’ present below average results and poor performance and need to be improved in regard to making the company more lean. Kanikuła & Koch, (2010) developed nine Kanban replenishment scenarios. Moreover, this study examined techniques and methods like One Piece Flow, Visual Control, Pull System, SMED, TPM, Kaizen, Glenday Sieve, and Value Stream Mapping. In this research, several boundary conditions were defined. Such conditions are distinguished by Guide Jr, (2000) as the major challenges that influence and complicate PPC activities within the remanufacturing industry. Kanikuła & Koch, (2010) has highlighted that future research should test identified scenarios in the remanufacturing business. Kurilova-Palisaitiene, Sundin and Poksinska, (2018) noted that ‘A great improvement resulting from the transformation of the ordering system to Kanban is control of the inventory level at the remanufacturing site’ although none of the companies in the study had implemented that tool.

In 2015 Kurilova-Palisaitiene and Sundin, (2015), also suggested that lean efforts might bring benefits to the remanufacturing case company. Based on the current state map and problems identified during the workshop in a German remanufacturer the pull Kanban reordering system was suggested. They claimed that the implementation of lean efforts might reduce lead time by even 69%. Studying material flow, Hunter and Black, (2007) investigated a cellular layout in remanufacturing. They proposed a cellular layout for the recovery of the production environment and claim that this solution can help to achieve a higher level of productivity and reduced inventories.

Moreover, Kurilova-Palisaitiene, Sundin and Poksinska, (2018) added that one way to accomplish continuous flow is to apply a cellular layout. They noticed that '*a cellular factory layout for continuous flow is beneficial in terms of solving the high inventory levels challenge and, together with the Kanban ordering system, has the greatest effect on lead-time reduction.'.* In addition, Kurilova-Palisaitiene, Sundin and Poksinska, (2018) have noticed that *'A cellular layout allows quick adjustments in the number of employees at the work stations*.

Kurilova-Palisaitiene, Sundin and Poksinska, (2018) states that *'by communicating in the standard way, the challenges related to the core and spare part information flow can be diminished.'* They also suggest that the introduction of instructions might reduce uncertainties related to the task being performed. To achieve that aim both images and text can be used. However, Amezquita & Bras, (1996) noticed that because of the stochastic nature of returned products, traditional remanufacturing processes are difficult to standardise.

Kurilova-Palisaitiene, Sundin and Poksinska, (2018) developed suggestions to tackle remanufacturing challenges with the aim of delivering shorter lead times. Potential improvements have been identified as a result of focus group interviews in their studies. Kurilova-Palisaitiene, Sundin and Poksinska, (2018) has highlighted that lean tools should be tested and verified at remanufacturing companies. Observed relations are presented in Table 2-2.

Table 2-2 The relationship between case companies' challenges and lean improvements. Source: Kurilova-Palisaitiene, Sundin and Poksinska, (2018).

Companies' remanufacturing process challenges	Lean-based improvements						
	a) Standard operations, instructions or/and checklists	b) Contin-uous flow	c) Kanban	d) Team-work	e) Factory layout for continuous flow	f) Employee cross-training and learning through problem solving	g) Supplier partnership
1. Lack of material requirements planning system	X	X	X	x	x	x	x
2. Poor core information	X	X	X	X	x	x	X
3. Lack of core material	x	X	X	x	x	x	X
4. Poor spare parts information	X	X	X	X	x	x	X
5. Lack of spare parts material	x	X	X	x	x	x	X
6. Insufficient quality management practices	X	x	x	x	x	X	x
7. Large inventories	x	X	X	x	X	x	x
8. Stochastic remanufacturing processes	x	X	x	X	X	x	x
9. Lack of supply-demand balance	x	X	X	x	x	x	X
10. Insufficient automation	x	x	x	x	x	X	x

Some researchers have also noticed existing restrictions and difficulties with the application of lean tools and methods within the remanufacturing environment. Pawlik, Ijomah, & Corney, (2013) identified that within the automotive sector, the uncertainties involved with incoming cores can be a factor in reason unsuccessful implementations. A similar conclusion was reported by Ostlin & Ekholm, (2007) regarding a toner cartridge remanufacturer. It was observed that the variable processing time and uncertainties in materials recovered to limit the implementation of the lean approach. Seitz & Peattie, (2004) claimed that the differences between the challenges for conventional manufacturing and remanufacturing are significant. These complications are mainly involved with different product generations and numerous different variants. Thus remanufacturers are mainly working with small batches that allow encompassing that difficulty. In contrast to remanufacturers, manufacturing companies usually have to deal with one generation of product at a time that allows dedicating production lines to a single type of product. Due to the above '*establishing the types of lean and mass production systems that manufacturers depend upon becomes practically impossible.'* However, there is a lack of evidence that company CarCo, used in their research, made an attempt to apply any of lean tools or principles.

Pascual et al., (2020) presented the collaboration between the University of Valladolid and Renault-Nissan Consulting. The factory training that integrates lean manufacturing and the circular economy was discussed. Training is given not only to students but to workers and professionals. It was highlighted that this cooperation is currently very important. Due to limited resources, effective use must be ensured.

Table 2-3 highlights all lean applications in the remanufacturing environment.

Table 2-3 Summary of lean remanufacturing literature

Year	Author	Sector	Main Lean Practices Discussed	Outcome
1996	Amezquita & Bras	automotive remanufacturer	elimination of non-value-added activities, standardisation	The current batch of remanufacturing oriented processes for an automobile clutch was studied and a lean remanufacturing process that is more robust and has lower cost was proposed.
2004	Seitz & Peattie	automotive remanufacturer	Standardisation	They claimed that the differences between the challenges for conventional manufacturing and remanufacturing are significant.
2006	Sundin	toner cartridges, household appliances, camera, automotive, remanufacturers	The Rapid Plant Assessment	The result of this study shows that the remanufacturer performs well in categories: ‘Customer satisfaction’, ‘People Teamwork’, ‘Skill Level and Motivation, ‘Ability to Manage Complexity and Variability’ and ‘Quality System development’
2007	Ostlin & Ekholm	toner cartridge remanufacturer	The Rapid Plant Assessment, Value Stream mapping	The variable processing time and uncertainties in materials recovered to limit the implementation of the lean approach
2007	Hunter & Black	mobile phone remanufacturer	cellular manufacturing	They proposed a cellular layout for the recovery of the production environment and claim that this solution can help to achieve a higher level of productivity and reduction of inventories

2008	Kucner	naval ship repair industry	5S, standardisation, standard work, kanban, andon, takt time, kaizen events. FIFO, pull system	Several examples of successful applications of lean tools and practices within the naval ship repair industry presented. Lean methods significantly improved performance, particularly in developing internal process stability, build–in quality and just in time production.
2010	Kanikula&Koch	automotive remanufacturer	Kanban, One Piece Flow, Visual Control, Pull System, SMED, TPM, Kaizen, Glenday Sieve, and Value Stream Mapping.	They developed nine Kanban replenishment scenarios. Moreover, this study examined techniques and methods like One Piece Flow, Visual Control, Pull System, SMED, TPM, Kaizen, Glenday Sieve, and Value Stream Mapping.
2013	Pawlik, Ijomah, & Corney	automotive remanufacturer	TPM, standardised work instructions, visual management, 5S, OEE	It was confirmed that the application of lean manufacturing within remanufacturing operations can bring significant benefits including a reduction in lead-time, reduced work in process, improved on-time shipments, increased utilization of floor space, improved quality, increased production control
2015	Kurilova - Palisaitiene and Sundin	automotive remanufacturer	Kanban	They suggested that lean efforts might bring benefits to the remanufacturing case company. Based on the current state map and problems identified during the workshop in a German remanufacturer the pull Kanban reordering system was suggested. They claimed that the implementation of lean efforts might reduce lead time by 69%
2018	Kurilova - Palisaitiene, Sundin and Poksinska	automotive and IT remanufacturer	Continuous flow, Kanban, teamwork, employee cross-training, problem-solving	Suggestions to tackle remanufacturing challenges with the aim of shorter lead time have been developed
2020	Pascual et al.	academia	Lean training	It presented the collaboration between the University of Valladolid and Renault-Nissan Consulting in regards to providing lean training that is integrated with a circular economy.

2.4.1 Waste in the Remanufacturing Environment

The significant component of Lean is the concept of value thus it is important to reconsider the commonly held paradigms of the value-added and non-value-added activities, with regards to the remanufacturing context. Remanufacturing is clearly adding value to the products, which were meant to be discarded, in terms of lifecycle value. However, it is important to look closely into the inefficiencies that occur during the process. It can be seen that in remanufacturing some of the operations do not add value. Moreover, it seems that a higher percentage of operations that transform the product but do not add value to the final customer occurs in remanufacturing than in conventional manufacturing. The inspection was classified as one of them (Kucner, 2008) while at the same time it is a crucial stage for the remanufacturing process (Errington and Childe, 2013). Moreover remanufacturing always requires 100% inspection, in contrast to conventional manufacturing, where sampling methods are often used (Brent and Steinhilper, 2004). Disassembly is another operation that does not add value to the final customer and in addition might be seen as a reduction of the inherent value of used products (Kucner, 2008).

The elimination of waste is the primary objective when creating a lean process (Liker and Meier, 2005) and the following 7 types of waste, identified by Toyota, were reassessed with regards to the remanufacturing process.

1. **Overproduction** is the most significant aspect also in the remanufacturing environment. It mainly occurs as the remanufacturers usually disassemble cores before the (internal) customer order, to determine the condition of the components (Kucner, 2008).

2. **Waiting** (time on hand), similar to conventional manufacturing this waste can be found in many forms such as employees watching automated machines and cannot proceed until the machine is finished cycling, or during machine downtime.

3. **Transportation or conveyance**, very often cores are disassembled in the facility and then components are transported to the other industrial locations for repair and reprocessing (Kucner, 2008). This waste also occurs when components, after disassembly, are carried to the store, then when customer order appears, parts are then moved from the store to the reassembly place, resulting in increased transportation. Moreover when there is a missing part or the part does not fulfil the expected quality, the core is transported to the store or the previous operation.

4. **Overprocessing or incorrect processing**, many large and extremely expensive products are remanufactured. Some of these products are no longer in production and replacement of the components doesn't exist. That is why many remanufacturers tend towards expensive technical operations beyond economic justifications while processing critical components.

5. **Excess Inventory** represents significant waste in remanufacturing and most of the remanufacturers report that they struggle with the excess inventory of cores, WIP, and remanufactured products. Remanufacturers do not have influence over when a product will be returned to the facility, this forces them to keep a higher level of the inventory against the variability in supply and demand (Guide Jr, 2000). In many instances, the remanufacturers don't examine and refresh their inventories to remove obsolete products. They want to keep them 'just in case'. Moreover, because the quality of the components can be uncovered when the product is disassembled,

remanufacturers prefer to do that earlier, which results in high Work in Progress (Kucner, 2008). In addition, the uncertain quality of the components results in imprecise times to carry out operations. As a strategic buffer against this variability, many remanufacturers will maintain significant levels of inventories between operations.

6. **Unnecessary Movement** similar to conventional manufacturing employees perform movements that do not add value to the product. Particularly collecting used and new parts together require lots of unnecessary walking as each product might need different sets of new components.

7. **Defects** According to J. Liker & Meier (2005) a defect is considered when 'production of defective parts or correction' occurs. Does it mean that if the remanufacturer can't eliminate an existing fault that this is treated as a defect? Products are delivered to remanufacturers with the defects. There is a need to reconsider the meaning of defect in the remanufacturing process.

Another type of waste that was identified later is **unused employee creativity**. In remanufacturing it might be more difficult to use employees' creativity as the process that happens on the shop floor is less repetitive. If the process is not performed regularly, even a few times a year, improvement initiatives might not be developed (Kucner, 2008).

2.5 Summary of the Literature Review

Previous researchers have highlighted that compared with the original manufacturing process, remanufacturing has more uncertainties. Guide (2000) and Junior and Filho, (2011) have detailed the challenges that remanufacturing companies are facing. To improve the competitiveness of remanufacturing enterprises the uncertainties of remanufacturing should be overcome. Matsumoto *et al.*,(2016) have indicated that because operations management is more complex than conventional manufacturing, research on forecasting, product scheduling, capacity planning, production planning, inventory management is required to support developing efficient and effective remanufacturing systems. Junior & Filho (2011) stated that there is a clear need for more practical research (e.g. case studies) into the challenges and the shop floor control activities in remanufacturing. Lean remanufacturing has become a new research direction to improve the performance of remanufacturing (Kucner, (2008); Pawlik, Ijomah and Corney, (2016); Kurilova-Palisaitiene, Sundin and Poksinska, (2018)). The study done by Kurilova-Palisaitiene, et al. (2018) attempted to tackle remanufacturing challenges using lean practices. Potential improvements have been identified as a result of focus group interviews in their research. Kurilova-Palisaitiene et al. (2018) have highlighted that the discussed lean tools should be tested and verified at remanufacturing companies and there is a need for more empirical research to examine the connection between the application of lean manufacturing practices and the challenges which occur within remanufacturing shop floor activities (Kurilova-Palisaitiene, Sundin and Poksinska, 2018). Seitz & Peattie (2004) have also stated that there is a need for more empirical research in the automotive environment. Consequently, this research identified a gap in literature which will be further addressed through empirical work in the following chapters.

Research Gap 1: Limited knowledge on how the applications of lean practices reduce the impact of complexity on production planning and control in remanufacturing processes.

Therefore, this research investigates the following research question.

RQ 1: How does the application of lean practices reduce the impact of the complexity of production planning and control in the remanufacturing processes?

Unsuccessful applications of lean within the remanufacturing process have been identified in the literature. Pawlik, Ijomah, & Corney, (2013), Ostlin & Ekholm, (2007) Amezquita & Bras, (1996) Seitz & Peattie, (2004) have reported some limitations. The factors that limit the application of lean tools within conventional manufacturing have been widely described in the existing literature. However limited research is available regarding limitations of applying lean within the remanufacturing context which was identified as a research gap in literature (E. Pawlik, Ijomah and Corney, 2013).

Research Gap 2: Limited knowledge about the application limits of lean practices within the remanufacturing process.

Hence, this research explores the following research question:

RQ2: How does the complexity of the remanufacturing process limit the application of lean practices?

The conceptual framework (Figure 2-7) has been developed to put together the main points from the literature. It will guide further empirical research.

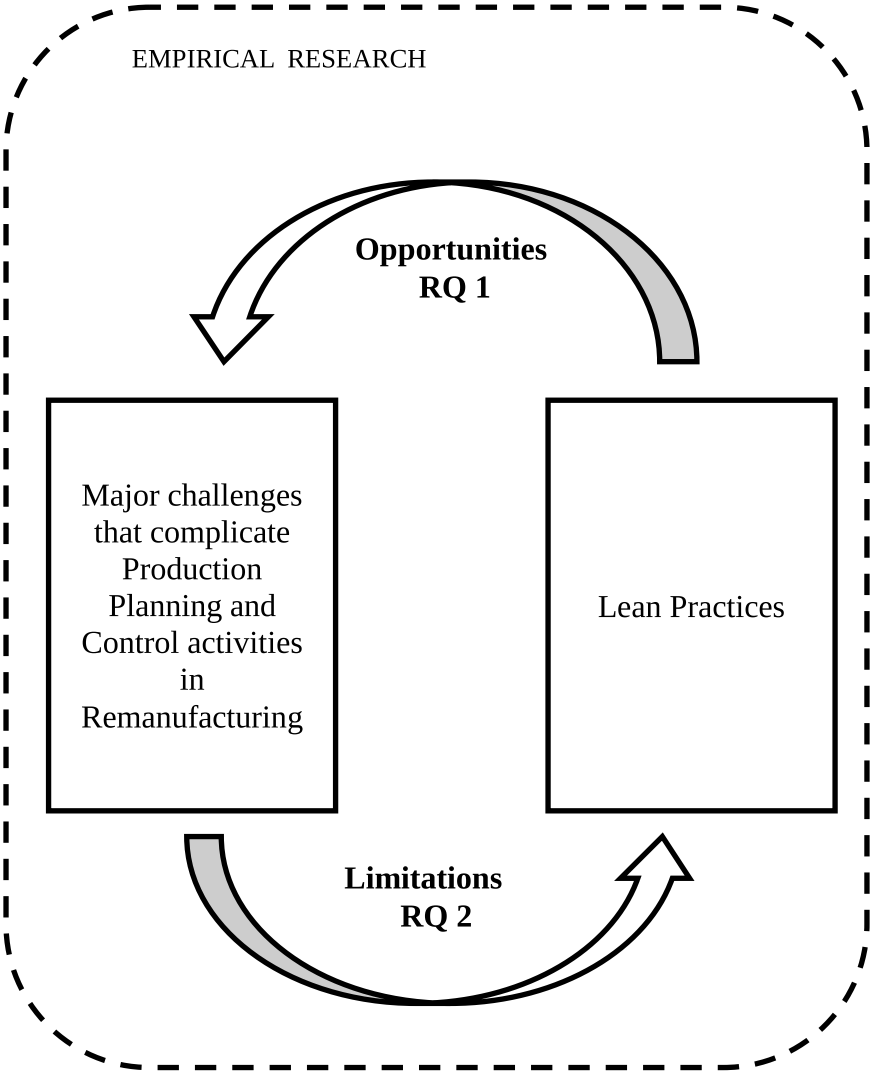

Figure 2-7 Conceptual Framework

3 Research Design

The research design is about organising research activity, including the collection and analysis of data to conduct a reliable and robust empirical investigation. A wide range of possible methodologies and data gathering methods are available with associated strengths and weaknesses. None of them can be considered good or bad, but some will be more suitable than others for a particular research area and research questions. Moreover, the choices that were made regarding the research design have been influenced by the worldview of the researcher. Central to this research is the collection and analysis of empirical data on the process of using the lean concept in the remanufacturing environment.

3.1 Research Philosophy

Researchers approach their inquiries with a certain worldview as a basic set of beliefs and assumptions which guide their study. The most common debate regarding research philosophy concerns ontology and epistemology. The researcher is faced with questions related to the nature of reality and the relationship of the researchers to that being studied (Bryman *et al.*, 1988; Guba and Lincoln, 1994). The philosophical assumptions help the researcher to choose the right research methodology. A lack of awareness of research philosophy options might reduce the quality of the research (Easterby-Smith, Thorpe and Jackson, 2012).

3.1.1 Ontology

Ontology is concerned with the nature of reality (Easterby-Smith, Thorpe and Jackson, 2012; Creswell and Creswell, 2017). Depending on what is considered as a fact, the particular type of information must be collected and analyzed in a particular way. Table 3-1 gives an overview of the ontology.

Table 3-1 Ontology Overview Source: Easterby-Smith et al., (2012)

Ontology	**Realism**	**Internal Realism**	**Relativism**	**Nominalism**
Truth	Single Truth	Truth exists but is obscure	There are many 'truths'	There is no truth
Facts	Facts exist and can be revealed	Facts are concrete, but cannot be accessed directly	Facts depend on the viewpoint of the observer	Facts are all human creation

Realism highlights that the world is external and 'that *science can only progress through observations that have a direct correspondence to the phenomena being investigated'*. The researcher cannot affect "truth".

Internal Realism postulates that *'there is a single reality, but asserts that it is never possible for scientists to access the reality directly*' (Easterby-Smith, Thorpe and Jackson, 2012). Internal realism claims that *'scientific laws once discovered are absolute and independent of further observations'* (Easterby-Smith, Thorpe and Jackson, 2012).

Relativism claim that '*scientific laws are not simply out there to be discovered, but that they are created by people'* (Easterby-Smith, Thorpe and Jackson, 2012). The "truth" is the result of several discussions, considerations and viewpoints between people and in consequence can be influenced by the political and business environment.

Nominalism postulates that '*the answer in our view depends both on the topic of enquiry and the preferences of the individual researcher'* (Easterby-Smith, Thorpe and Jackson, 2012). It says that a single "truth" does not exist and it is developed through human thought and interaction.

3.1.2 Epistemology

Epistemology is associated with the relationship of the researcher to that being studied. It is related to the different ways of inquiring into the nature of the world. A researcher has to select a suitable epistemological position for which to structure their investigations (Easterby-Smith, Thorpe and Jackson, 2012). At the centre of management research, debate exists around two contrasting views: positivism, and social constructionism. Table 3-2 presents a comparison of these two approaches.

Table 3-2 Positivist/Social constructionist. *Source:* Easterby-Smith et al., (2012)

	Positivism	**Social Constructionism**
The observer	Must be independent	is part of what is being observed
Human interests	Should be irrelevant	are the main drivers of science
Explanations	Must demonstrate causality	aim to increase general understanding of the situation
Research Progresses through	hypotheses and deductions	gathering rich data from which ideas are induced
Concepts	need to be defined so that they can be measured	should incorporate stakeholder perspectives
Unit of analysis	should be reduced to the simplest terms	may include the complexity of 'whole' situations
Generalization through	statistical probability	theoretical abstraction
Sampling requires	large numbers selected randomly	small numbers of cases chosen for specific reasons

Positivism indicates that the world is independent of the researcher. The phenomenon should be studied objectively without being affected by the thoughts, feelings and personal beliefs of the investigator (Easterby-Smith et al. 2012). Properties of the subjects should be measured quantitatively and simplified into its smallest element to enable a better understanding of the problem.

Social constructionism is derived from the belief that reality is not independent, rather, the reality is created socially by people, who contribute a certain meaning. Researchers do not focus on the external facts that are available to them; rather, they highlight the process of how people communicate and interact (Easterby-Smith et al. 2012).

Easterby-Smith et al. (2012) have defined the link between ontology and epistemology that is summarised in Table 3-3.

Table 3-3 The correspondence between Ontology, Epistemology and Methodology. Source: Easterby-Smith et al., (2012)

Ontologies	**Realism**	**Inter Realism**	**Relativism**	**Nominalism**
Epistemology / **Methodology**	**Strong Positivism**	**Positivism**	**Constructionism**	**Strong Constructionism**
Aims	Discovery	Exposure	Convergence	Invention
Starting points	Hypothesis	Propositions	Questions	Critique
Designs	Experiment	Large surveys; multi-cases	Cases and surveys	Engegement and reflexivity
Data types	Numbers and facts	Numbers and words	Words and numbers	Discourse and experiences
Analysis/ Interpretation	Verification/ falsification	Correlation and regression	Triangulation and comparison	Sense-making; understanding
Outcomes	Confirmation of theories	Theory testing and generation	Theory generation	New insights and actions

3.2 Methodology

An important step in any research project is the choice of methodology. The methodology describes the research process and its purpose is to act as an effective structure for undertaking the tasks specified in the research design (Easterby-Smith, Thorpe and Jackson, 2012). The methodology must complement the philosophical assumptions of the paradigm upon which the research design is based (Creswell and Creswell2017).

Thus the choice of ontology and epistemology influences the choice of methodology and methods used in a research study. Literature reports a wide range of methodologies available for researchers. Following Relativism and Constructionism paradigms, an appropriate methodology to use for this research seems to be a 'case study' approach because it allows the retention of the holistic and meaningful characteristics of real-life events (Yin, 2003). The limited knowledge of theoretical and empirical linkages between lean tools and remanufacturing is a key motivation for this study, at best and with anecdotal reports and no quantitative data to test, the investigation required "real life" data from people working in remanufacturing. Interacting and communicating with participants using lean tools allowed for the "truth" to surface and substantiated the study (Easterby-Smith et al, 2012). Since such "truths" may vary from process to process several viewpoints to draw on were required to demonstrate that lean tools offer advantages in the remanufacturing context (Easterby-Smith et al, 2012). A methodology offering flexibility and triangulation in data collection whilst supporting the relativist and social constructionist approaches, allowing the iteration of data collection and analysis and revision of the research question resulted in following the case study methodology (Bryman, 2012; Silverman, 2005).

3.2.1 Case Study

In Chapter 2, the Literature Review, previously reported work done on the application of Lean in the context of remanufacturing and the observation made that there is still a lack of an empirical perspective on the field. Lean remanufacturing is a novel field and there is a paucity of data and publications. Consequently, a greater research effort is required to investigate the influence of Lean tools and principles on the complexity of production planning and control in remanufacturing processes. The case study methodology is an effective method for capturing qualitative data (Kathleen M Eisenhardt, 1989; Creswell and Creswell, 2017). Yin (2003) highlighted that *"case studies allow an investigation to retain the holistic and meaningful characteristics of real-life events such as organizational and managerial processes"*. Thus the case study approach is often used to contribute to the knowledge of the individual, group, organizational, social, political and related phenomena and allow the understanding of complex social phenomena (Yin, 2003). A research problem requires an extensive and 'in-depth' investigation and therefore this approach is suitable for this study.

Thus case studies are recommended method when:

- the researcher has minor control over events,
- the focus is on an existing phenomenon surrounded by some real-life context. (Yin, 2003).

The case study approach offers many advantages for theory-building purposes by using the multiple data collection techniques and the constant testing of the emergent theory during its development Romano (1989) and Lang and Heis (1994). Moreover, the constant testing of achieved results increases the validity of the research. It is particularly important because lean remanufacturing is a novel field for which there is a lack of publications against which the findings can be assessed.

Furthermore, a case study is the suggested method when 'how' and 'why' research questions are being examined (Gräbner and Eisenhardt, 2007). 'How' research questions have been investigated in this study:

1. **How does the application of lean practices reduce the impact of the complexity of production planning and control in remanufacturing processes?**
2. **How does the complexity of the remanufacturing process limit the application of lean practices?**

Case studies can be used for various research purposes. The types of case studies are (Voss 2010; Yin 2003):

- Explanatory case studies try to *'determine whether event x led to event y'*. It was highlighted that in doing this type of research it is very important to take into consideration all variables that might cause y. This study should be traced over time, rather than focusing only on frequencies (Yin, 2003).
- Descriptive case studies should be used *"where the objective is to describe the real-life context in which the investigation has been undertaken*" (Ijomah, 2002).
- Exploratory case studies are commonly used in management research. The goal is *'to develop pertinent hypotheses and propositions for further inquiry'* (Yin, 2003).

Depending on the characteristics of the research questions, this case study can be categorised as either exploratory or descriptive types of research. This is because the purpose of this study includes:

- Developing a Matrix that presents the relationship between lean tools /principles and the complexity of production planning and control in remanufacturing that would be the foundation for further remanufacturing research.

- Describing the use of lean tools and principles within the remanufacturing so that others will understand it.

This research follows the common approach for case study research influenced by the work of Eisenhardt (1989a) and Yin (2003). Although the case study is widely known and used a form of inquiry, some researchers see it as less desirable. The main argument for this opinion is a lack of objectivity and rigour involved in this type of research. In response to this criticism, Kathleen M Eisenhardt, (1989) points out that a systematic procedure to guide the data collection and analysis stages should be adopted.

Platts (1993), Chase (1980), Susman and Evered (1978), Buffa (1980), Hill (1987) and Meredith et al. (1989) highlighted that too much attention has been put on research methods and techniques while the needs of the industry haven't been sufficiently covered. The methodology chosen for this research must assure that findings would be beneficial to remanufacturing practitioners. Kathleen M Eisenhardt's, (1989) theory-building approach is appropriate to satisfy the practitioners' needs because its empirical evidence and thus findings are based on the practitioners' reality. It also allows direct research on practitioners' most significant needs. Table 3-4 and the following paragraphs present Kathleen M Eisenhardt, (1989) framework and explain how it was used in this research.

Table 3-4 Process of Building Theory from Case Study Research (Kathleen M Eisenhardt, 1989)

Step	Activity	Covered in this research
Getting started	Definition of research questions	**Chapter 2** – Literature Review, **Chapter 3** – Pilot Case Study
Selecting cases	Specify population - theoretical, not random sampling	**Chapter 4.5** – Pilot Case Study
Crafting Instruments and protocols	Create multiple data collecting methods that allow multiple investigators to collect data	**Chapter 4.6** – Field Work: The Pilot Case Study
Entering the field	Overlap data collection and analysis.	**Chapter 5** – Field Work: Case Study Research
Analyzing data	Analyze within a case and across cases	**Chapter 5.5**: Cross-Case Study, **Chapter 6**: Discussion
Shaping hypotheses	Iterate tabs for each construct and replicate	**Chapter 6**: Discussion
Enfolding Literature	Compare with conflicting and similar literature	**Chapter 8**: Conclusions and Further Research
Reaching Closure	End process iteration when marginal improvement becomes small	**Chapter 8**: Conclusions and Further Research

Voss (2010) has highlighted that Production and Operations Management (POM) is concerned with the combination of processes, operating decisions, procedures, company policies and technologies to increase the competitiveness of the facility. This research aims to provide a detailed understanding of the relationship between lean efforts and complexities of production planning and control in remanufacturing identified by existing literature and thereby allow remanufacturing companies to better use their resources. For this reason, the researcher believes that the work lies in the domain of POM research. The methodology selected for this research must, therefore, be appropriate for POM research. Eisenhardt's case study framework has been developed for organisational research and POM research.

The concern about the case study methodologies is the lack of generalizability that this approach provides. An often asked question is how can generalizations from one case be representative of all cases? In response, Eisenhardt (1989b) suggested that a multiple case study is the most appropriate method to provide generalizability as the evidence from individual cases can be compared (Kathleen M Eisenhardt, 1989; Romano, 1989). There are no strict rules on how many cases should be involved in a multiple case study, however, Eisenhard recommends between 4 and 10. Too few cases make it harder to generalise the findings but using too many, might results in the researcher only managing to touch the surface the problem being investigated. In response to the criticism concerning the lack of generalizability, we will use a multiple case study approach and collect data from various sources.

3.3 The Pilot Case Study

Before the final articulation of the research questions, a pilot case study was conducted to provide insight into the lean remanufacturing topic. According to Yin (2003), a pilot case study should be conducted to improve the data collection plan concerning the content of data and procedures that will be used. The scope of the study was broader and less focused than the later data collection activities. The main criteria for selecting a pilot case company were:

- type of business – remanufacturer
- experience with the application of lean – established a lean practitioner

The pilot case report contains not only information concerning the application of lean within the case company but also lessons learned for both research focus and data collection procedures. Parallel to the empirical research the literature review was conducted. In the result, the final research design was influenced by both the results of the empirical research and the relevant literature.

3.4 Case Study Protocol

To ensure that the data was collected in a repeatable and reliable manner, the case study protocol was developed and applied. According to Yin (2003) developing a Case study protocol is particularly important in multiple case study research when it is an important factor in the 'reliability' of the study.

Generally, a case study protocol contains the following sections (Yin, 2003) :

- An overview of the case study project,
- Field procedures
- Case study questions
- A guide for the case study report

Essentially a case study protocol ensures the use of a standard format for case study descriptions. The draft of case study reports was done as soon as possible after the case study was performed, and reviewed by key informants, which assured the validity of the case studies conducted as part of this study.

3.5 Selecting Cases

Case companies are not randomly sampled but rather selected according to their theoretical characteristics and how these can contribute to the research question. (Glaser and Strauss, 1967; Kathleen M Eisenhardt, 1989; Siggelkow, 2007). The selection criteria were:

1. Remanufacturers from the automotive sector. Remanufacturing is carried out across a wide range of industries ranging from textiles, construction, and electronics. It was reported that the automotive sector is the largest

remanufacturing sector, which accounts for about two-thirds of global remanufacturing activities ('Remanufactured goods: An overview of the U.S. and global industries, markets, and trade', 2013).

2. Companies experienced in the implementation of lean within their facilities. To evaluate the application of the Lean manufacturing philosophy in remanufacturing environments it is necessary to visit companies that already have experience with Lean tools and principles. All type of experiences is relevant for this research.

The method of identifying companies to take part in this research was executed through an Internet search. Each company was contacted over the phone or by email. Then a formal letter asking for permission to conduct research at the company was sent out and a suitable date for the case study visit was arranged.

The case companies under the study are (Table 3-5):

- **Pilot Case Company** – remanufacturer from the automotive sector based in the UK. The company was used in the pilot case study research to identify potential needs for future research.

- **Company A** – involved with the business of automotive remanufacturing based in the UK. The company was used to collect relevant data.

- **Company B** - involved with the business of automotive remanufacturing based in the UK. The company was used to collect relevant data.

- **Company C** - involved with the business of automotive remanufacturing based in Poland. The company was used to collect relevant data.

- **Company D** – involved with the business of automotive remanufacturing based in the UK. The company was used to validate the case study results.

Table 3-5 Overview of Case Companies

Case	Business sector	Business type	Location
Pilot Case Company	Automotive	OEM & Contracted	UK
Case A	Automotive	OEM	UK
Case B	Automotive	Contracted	UK
Case C	Automotive	OEM	Poland
Case D	Automotive	OEM & Contracted	UK

Three more companies have been visited however the results have not been used during the data analysis stage for the following reasons:

- Company E – involved with the business of automotive remanufacturing based in the UK. Company E is independent remanufacturer that has not implemented lean tools or principles within their facility.

- Company F – involved with the business of automotive remanufacturing based in Poland. Company F is an independent remanufacturer that has not implemented lean tools or principles within their facility.

- Company G – involved with the business of automotive remanufacturing based in the UK. Company G is an independent remanufacturer that has not implemented lean tools or principles within their facility.

Company E, Company F, Company G are from the sector of small-sized enterprises. Interviews with employees from these facilities showed that although they have some knowledge of Lean and are planning to apply this philosophy within their facilities in the future, however, it was not sufficient for these studies. The experience of the practical application of lean within remanufacturing companies is key for this research.

3.6 Unit of Analysis

The Unit of analysis presents the main focus of the research (Yin, 2003). Thus the relationship between Lean efforts and the complexity of production planning and control in remanufacturing is the main unit that is being investigated within this study.

3.7 Data Collection

This section aims to provide information on what techniques were used to collect relevant data. According to Gray, case studies require the use of multiple sources of evidence (Gray, 2007) and Yin proposed that case study evidence comes from six sources.

- Documentation
- Archival Records
- Interviews
- Direct Observations
- Participatory Observations
- Physical artefacts

A case study can use a variety of data collection methods such as interview, direct observation, access to documentation, which allow the researcher to capture the complex reality under investigation. Large quantities of information allow developing a rich picture of its nature (Romano, 1989; Gummesson, 1993; Chetty, 1996; Yin, 2003).

Interviews

Data collection was mainly based on semi-structured interviews with managers, engineers, and employees working in the case companies. Having several people (from each company) from different layers of management and staff increases the internal reliability of any conclusions drawn from the data. As suggested by Rubin (1995), the questions were led by the case study protocol. Interviews were recorded, when allowed, and shorthand notes were used when a recording was not permitted. Transcription of each interview was written down. Because interviews were conducted within each case company, it was a great opportunity to conduct observations

Direct Observation

According to Yin (2003), field visits create an opportunity for direct observation. Jim Womack claims that Gemba (in Japanese Gemba means 'actual place') is where you have to go to understand and learn. In this research observations were a valuable method of data collection. Because the interviews were conducted in each case company, the site visit was also organised. It allowed the researcher to do direct observations. The pictures were taken, when allowed. Once the researcher returned from case study visit the extensive text was written down and included within the case study report.

Documentation

Yin (2003) highlighted that gaining information from documents is relevant to every case study topic. In this study documents were accessed during the case study visit and through internet searching,

The strengths and weaknesses of the three sources of evidence used in this study are presented in Table 3-6.

Table 3-6 Six Sources of Evidence: Strengths and Weaknesses (Yin, 2003)

Source of Evidence	Strengths	Weaknesses
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of the study • Exact – contains exact data • Broad coverage – a long period, many events, many settings	• Retrievability can be difficult to find • Biased selectivity – if the collection is incomplete • Reporting bias – reflects (an unknown) bias of the researcher • Access – may be deliberately withheld
Interviews	• Targeted – focuses directly on case study topics • Insightful – provides perceived causal inferences and explanations	• Bias – due to poorly articulated questions • Inaccuracies – due to poor recall • Reflexivity – interviewee gives what the interviewer wants to hear
Direct observations	• Reality – covers events in real-time • Contextual – covers context of the case	• Time-consuming • Selectivity – broad coverage difficult without a team of observers • Reflexivity – event may proceed differently because it is being observed • Cost – hours needed by human observers

3.8 Data Analysis

This research follows a joint approach to data analysis influenced by the work of Eisenhardt (1989b) and (Miles and Huberman, 2009). (Kathleen M. Eisenhardt, 1989) recommended splitting the analysis into two main phases: First, conducting 'within-case-analysis' by taking out relevant information from each case; Then, conducting cross-case study analysis to develop generalizable knowledge by comparing the findings from each case. Miles and Huberman (2009) provide a more detailed approach by providing techniques for doing the analysis.

Their approach follows the parallel and repeated activities of data collection, data display, data reduction and drawing and verifying conclusions, see figure below (Miles and Huberman, 2009). Data collection activities were described in section 3.7 Data Collection. Both soft (from qualitative interviews and observations) and hard data (from numbers and graphs provided in documentation) were collected through a variety of data collection methods such as interview, direct observation and access to documentation.

Data reduction is a process of selecting, focusing, simplifying and transforming the data from field notes, interview transcriptions and company documents.

Codes are efficient data-labelling and data retrieval device. (Miles and Huberman, 2009). The aim of coding is to break the data and rearrange them into categories that assist in the comparison between things within the same category (Maxwell, 2012). This categorisation allows identifying patterns of data that leads to theory development (Eisenhardt and Graebner, 2007). Miles and Huberman (2009) recommended three methods for creating taxonomies that enable coding:

1. Codes derived from the conceptual framework (Figure 2-7) and the research questions of the study

2. Codes and the taxonomy are developed from data. This is a commonly used method in a grounded approach.

3. Creating codes at a general level and then letting codes emerge inductively.

In this study, codes were generated from research questions and existing literature on Lean Manufacturing and Remanufacturing. They were introduced at two stages of the analysis:

1. Within the case study analysis stage.

2. Cross-case study analysis stage.

Coding criteria for each step of analysis were presented below:

A. Within the case study analysis stage:

   a) Coding criteria: Lean tools and principles (or their synonyms):

      - Standardised work instructions
      - Standardization
      - Kanban
      - Cross-functional workforce
      - Production Analysis Board
      - 5S
      - Visual Management
      - Cellular Manufacturing
      - Total Production Maintenance

- First in First Out (FIFO)

B. Cross-case study analysis stage:

   a) Coding criteria: The complexity of production planning and control in remanufacturing defined by Guide Jr, 2000 and Junior & Filho, 2011 :

      - Disassembly of returned products
      - The complication of material matching restrictions
      - Uncertain timing and the number of returns
      - Need to balance returns with demand
      - The requirement for reverse logistics network
      - Uncertainty in materials recovered from returned items
      - Stochastic routings for materials
      - Highly Variable processing times

The next major process in data analysis is a data display. According to Yin (2015), data display includes matrices, graphs, networks, illustrations, tables, diagrams etc. In the first phase of this analysis, the first codes level, for each case the company transcript was applied. As a result, all of the lean tools and principles discussed was highlighted. Then the results were grouped into lean tools and presented in a table. The tables from all companies were combined. Then a second code level was applied. The major complexities of production planning and control in remanufacturing were highlighted. It allowed the identification of the relationship between lean and, so-called, complexities in remanufacturing. The identified relationship was assessed if a particular lean tool influences (or was influenced by) the complexity in remanufacturing. To display the data, matrices were used. Rows and columns for the matrices were constructed to explore the relationships between lean tools and complexity of production planning and control in remanufacturing. The final part of the analysis process is drawing and verifying conclusions. As it was presented in Figure 3-1, each component of the data analysis process is highly iterative and interdependent. The researcher goes back and forth between the steps to draw conclusions.

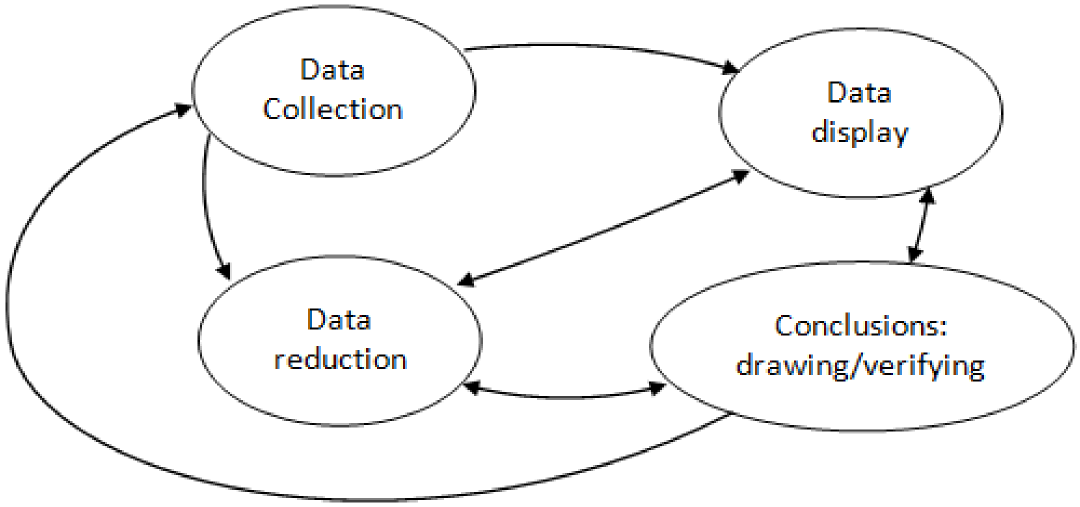

Figure 3-1 Components of Data Analysis (Miles and Huberman, 2009)

3.9 Ensuring Validity

In this research, a multiple case study approach was used because findings from multiple sources ensured a richer and more triangulated picture of the research problem. After each visit to a case company, a case study report was created. They were based on the various source of evidence such as interviews, observations and documents to enhance the reliability of collected data, as shown in Figure 3-2. Moreover, interviews with more than one person in each organisation were conducted to assure all facts gathered were accurate. This review process ensured the reliability of the case study findings.

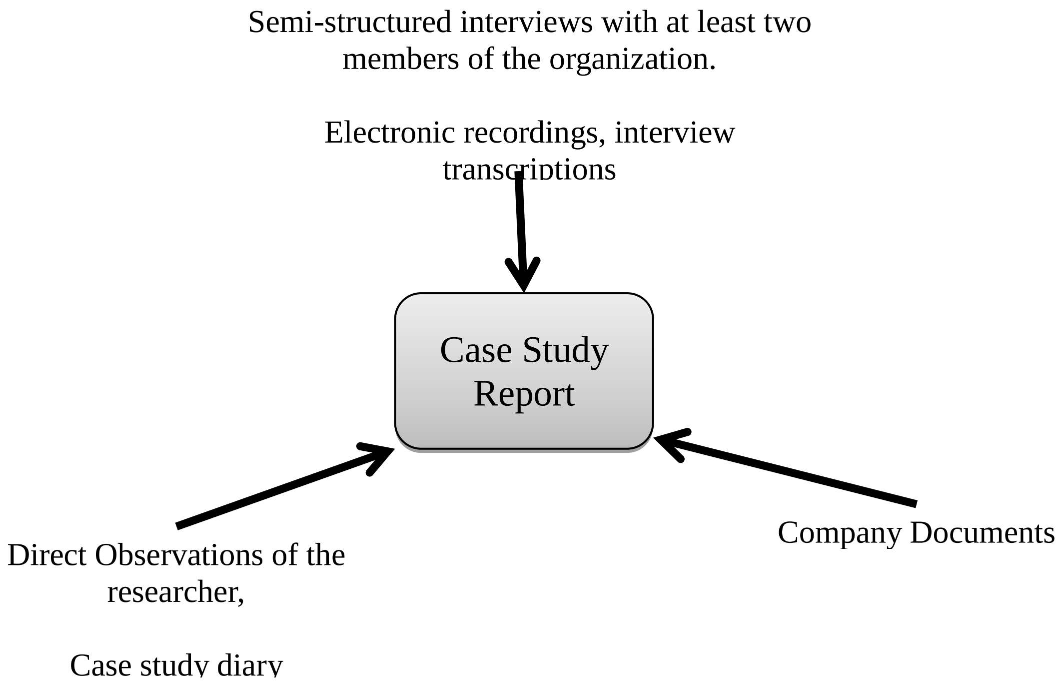

Figure 3-2 Triangulation of data in this study

Findings from this study were also presented to managers and employees from another company (Company D) for further feedback. Company D was selected for validation as its employees had experience with the application of lean within the remanufacturing environment

3.10 Summary

Figure 3-3 presents the research design for this research.

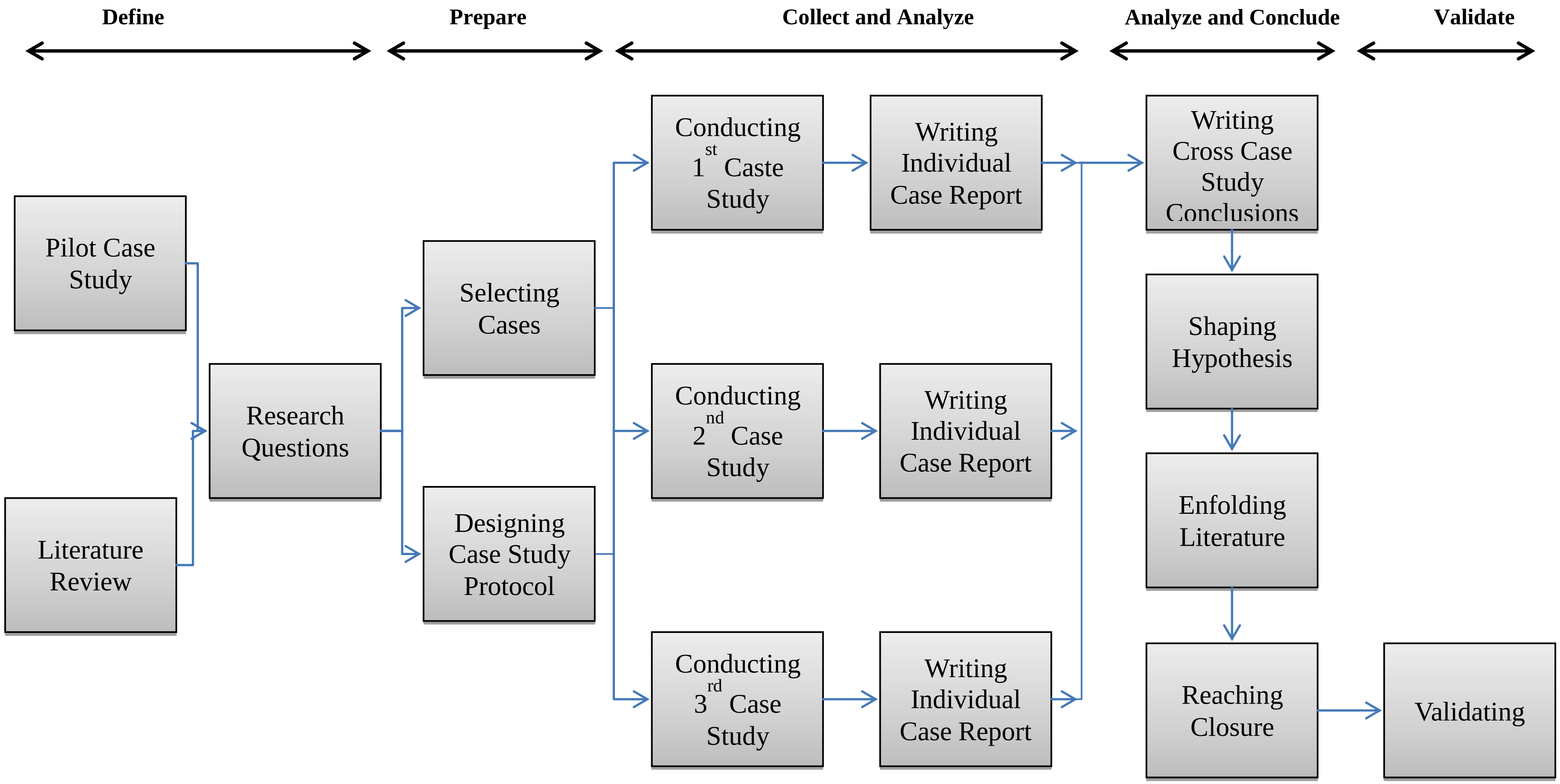

Figure 3-3 Research Design. Adapted from Eisenhardt and Graebner (2007; Yin (2003)

4 Field Work: Pilot Case Study

4.1 Chapter Overview

This chapter aims to examine lean remanufacturing practices within the existing industry to identify potential needs for future research as the existing literature is very limited.

Data collection mainly used primary sources of information like interviews and observations. Also, secondary sources were used (organisational charts, meeting minutes, reports and so on) and other information about the company from external sources (company's website) to triangulate data. During the three day visit at the facility, the interviews were conducted in two forms: First there were one-to-one interviews in an office or shop floor environment with managers; secondly there were interviews with production staff and team leaders while walking through the production floor (less formal). The questions asked were guided by Appendix I – Interview Questionnaire – Pilot Case Study and based on more of a conversational format rather than a rigid question and answer format. This approach allowed for in-depth discussions that put attention on important topics from the point of view of experienced interviewees. Due to the fact that the visit was carried out within the facility, the observation of the remanufacturing process (from disassembly to testing) was conducted as a primary data collection technique. In line with the confidentiality agreement pictures of the research, the site was not allowed to be taken. Moreover, accessing relevant documentation provided a valuable source of information into exploring the application of lean within the remanufacturing environment. From interviews, observations and documentation, extensive notes were taken and written up into a rich text once the researcher returned from the case study. The next section presents a summary of the data collected in the pilot case company.

4.2 Remanufacturing Process

Case study: Lean remanufacturing in Caterpillar

Caterpillar is both an OEM and contracted 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, they have access to the technical information on each component and control the aftermarket and intellectual property. The UK-based facility employees around 300 employees 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 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 4-1.

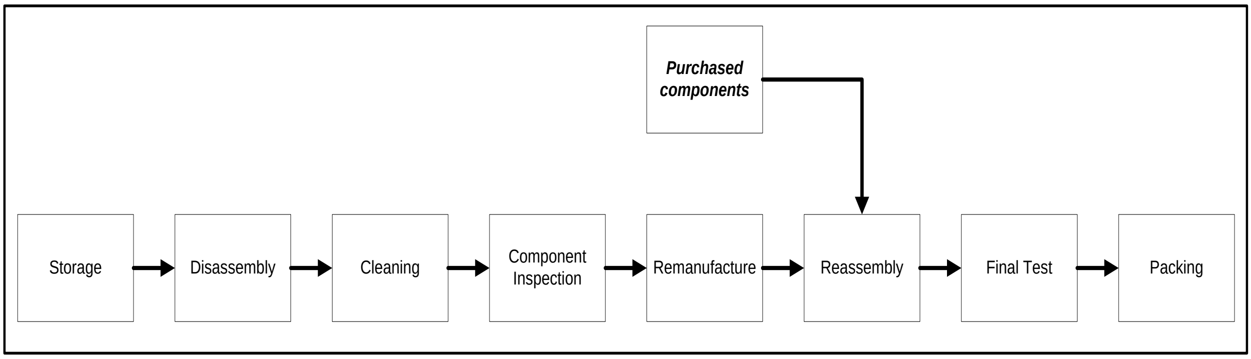

Figure 4-1 An overview of the remanufacturing process within Caterpillar.

Lean manufacturing methods were first introduced to 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 in 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, the 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.

Standardised 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 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. Standardised 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 acceptance 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 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 ten most common defects are also presented on the section metrics boards. All of these visual displays are used 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 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. Another example of visual management implemented within the facility is shadow boards. They define where particular hand tools or cleaning utensils should be placed when they are not in use. The manager has confirmed that shadow boards reduce time spent looking for tools and improve work station safety.

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 standardised 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 routines, 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 the ability to meet deadlines).

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.

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 the 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 on 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.

4.3 Conclusions from Pilot Case Study & Next Step

The pilot case study presents many examples of successful lean initiatives in the remanufacturing context. It was confirmed that standardised work instructions are particularly useful in the inspection process. Visual management has been effectively employed in the company and helps employees to communicate and eliminate significant waste and problems from daily tasks. Each identified problem is investigated and resolved by using the Ishikawa diagram, 5 Why and histograms. Other lean initiatives such as TPM and OEE help improve equipment reliability and allow quick identification of losses thus improving equipment productivity. Despite the advantages gained from implementing lean manufacturing tools and principles, it was detected that several tools haven't been effectively implemented. The manager highlighted that it was difficult to determine cycle times and pull systems. Moreover, the implementation of 5S was demanding, since operations on various components are carried out at the same workplace. As a result, there is a need to keep different tools at a workstation, which are not required regularly. The Production Manager said that '*remanufacturers are forced to learn from their own mistakes'*. The application of lean within the conventional manufacturing process has been widely described in existing literature however limited research is available regarding the application of lean within the remanufacturing context. It was highlighted that the remanufacturing process is more complex that is why it is important to focus on aspects that differentiate remanufacturing from conventional manufacturing. She highlighted that it is important for remanufacturing businesses to know what lean practices can be used in the remanufacturing context. Moreover, she said that *there is a need to identify what limits this application to get the most out of it.* The pilot case study examined lean remanufacturing practices within the existing industry that helped to identify potential needs for future research. The pilot case study allowed for the scope of the research to be narrowed to consider the relationship between lean efforts and the complicating characteristics of the remanufacturing process identified by existing literature. Moreover, this study improved the data collection plan concerning the content of the data and procedures used in further research. The scope of the pilot case study was broader and less focused than the later data collection activities.

5 Field Work: Case Study Research

This chapter presents the findings from each case company and the discussion of the relevant data. Key findings for each case company will be highlighted. Moreover, the data from all the case study companies are compared and contrasted to develop, generalizable knowledge.

5.1 Introduction

The findings of each case study are organised into four main sections. The first section presents an overview of the company containing information about the size of the business, history of the company, type of products that are remanufactured, the history of lean implementation in the company. The second section introduces the remanufacturing process and the challenges that complicate production planning and control activities. The third section relates to the lean tools and principles that were implemented within the case company, focusing on the benefits and challenges of applying Lean within that particular company. The fourth section summarises the lean practices implemented within each Company.

The entire process of remanufacturing from gate-to-gate was observed during case study visits to understand the overall process and application of lean tools and principles within the process. Visits in three case companies lasted around 2-3 days. Within that time, the entire sequence of remanufacturing operations (from disassembly to testing) was followed with field notes and photographs taken whenever possible (company A didn't agree to pictures being taken within their facility). The researcher has participated in the shop floor's daily activities. However, this role was limited to observing things that happened, listening to what was said and questioning peoples. These observations together with company documentation allowed an understanding of the complexities of each remanufacturing process. Sketches were made of the process flow which was used to develop the overall process flow diagrams. Moreover, interviews were conducted in two forms: First there were one-to-one interviews in an office or shop floor environment (with the Production Manager, Production Engineer, Planning Specialist, Continuous Improvement Manager); secondly there were interviews with production staff and team leaders while walking through the production floor. A semi-structured interview was guided by a set of open questions (developed as a result of a literature review and pilot case study research) presented in Appendix II - Interview Questionnaire. General issues were discussed at the beginning of each interview to introduce ourselves (the interviewer) and to get a better understanding of the case company. Then the set of open questions was asked to answer each of the previously stated research problems. The Interview Questionnaire was developed as a result of the literature review research and pilot case study research to increase the 'reliability' of multiple case study research. Data collection based on semi-structured interviews at each case company took approximately 10 hours. Each interview was recorded and transcribed.

Because of the need for commercial confidentiality each case company was anonymised and is referred to only as Company A, Company B, Company C. The next section presents a summary of the data collected in each case company through interviews, observations, and review of their internal documentation.

5.2 Case Study A

5.2.1 Introduction of Company A

Company A is a UK based OEM Remanufacturer based in Newcastle-upon-Tyne. At this facility, the company remanufactures hydro-gas suspension units, final drives, track tensioners and bridging equipment for combat vehicles (such as the Challenger II tank). With such vehicles serving in very testing climates and conditions, these parts are of course classified as high-wear items.

5.2.2 The remanufacturing process within Company A

***Source of Evidence: Interview, Observations & Company Documentation* -** The remanufacturing process starts with an assessment of individual cores to determine if they can be remanufactured or are beyond economic repair. Cores that can be remanufactured are disassembled and inspected at the same time. Then components are cleaned and again inspected to ensure that nothing was overlooked at the first inspection. Afterwards, components are put on a pallet and a Manufacturing Engineer creates a rebuild kit which is sent to storage, where it remains until such a kit is required for remanufacturing. Rebuild kits are classified as light, medium or heavy in terms of the work required to remanufacture that item. Introduction of the standardised kit system has made the planning process easier. Then components are reassembled and the remanufactured product is tested, packed and sent to the customer (Table 5-1).

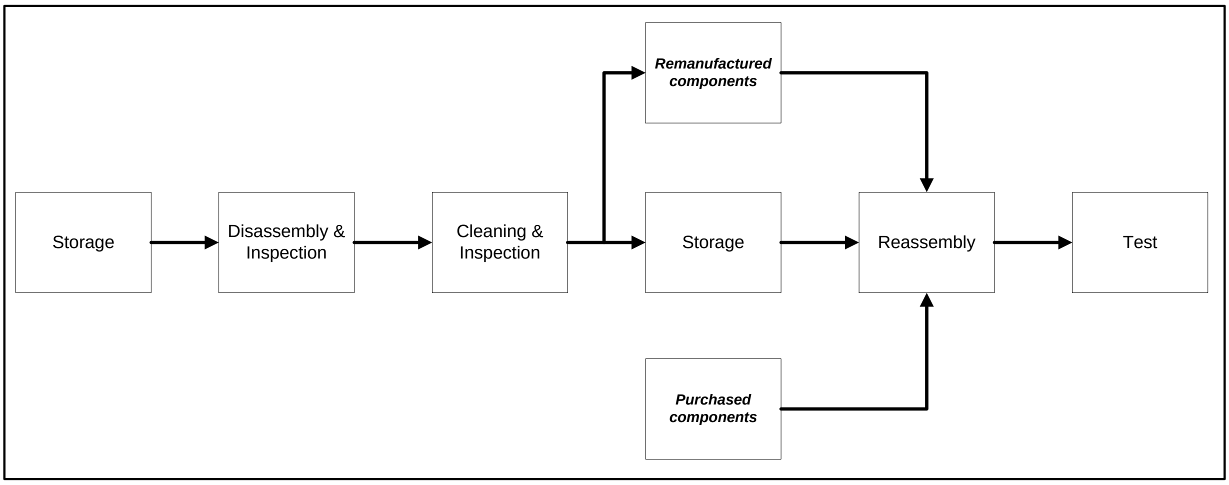

Table 5-1 Simplified overview of the remanufacturing process: Company A

***Source of Evidence: Interview* -** During the interviews, it was highlighted that the uncertainty of the quality of incoming cores has a significant influence on the remanufacturing process. When for example, a component is missing, the core cannot be remanufactured and consequently extra time, transport and paperwork are required to send it back. Similarly, a component that has been not properly evaluated might be sent to the next operation and eventually be removed. As a result, unnecessary work has to be done and the reassembly of the particular core has to be postponed to wait for the new component. To make the inspection process easier, quality standard references have been developed in response to employees suggestions. In conventional manufacturing, engineers remove as much variation as possible but in remanufacturing, there will always be some level of uncertainty that has to be dealt with. The highly variable processing time has an impact on the entire remanufacturing process and consequently, the company seeks to improve this continually. Thus a time had been defined for each operation and employees aim to work to that time. If they could not, they needed to ask for more time and the manufacturing engineers were informed why they are asking for more time. Based on that information managers and engineers solve existing problems and improve the process. When quality problems occur the extra process time is calculated and engineer and staff act on the issue in almost real-time. When necessary, further investigation is done by sending manufacturing engineers to discuss the problem with suppliers etc. Interviewed managers suggested that delivery time for new components complicate PPC because the company doesn't want to spend money upfront until the customer will agree to that. For example, seals are quite specialised and take 8-10 weeks to arrive this is critical because the remanufacturing process can only start after all the components have arrived. Similarly, uncertainty in the quantity and timing of incoming cores also influences the remanufacturing process. When the core did not arrive the employees are waiting and there is a need to create work for them. The manager said that without knowing when and what is coming in they cannot plan work efficiently.

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5.2.3 The application of Lean within Company A

Source of Evidence: Interview **-** Company A started to implement lean manufacturing principles within the Tyne & Wear facility in 2007. The interviewed manager said that in general there is some level of success in regards to the application of Continuous Improvement philosophy within the facility.

Source of Evidence: Interview & Company Documentation - Due to increased threats from competitors, Company A urgently needed to reduce the price of the remanufactured unit. To reduce internal cost, the company had organised a 5 day Kaizen workshop. The researcher didn't take part in this event. However, because it was a significant part of the lean journey point of view, the Manager presented every step of this workshop. Moreover, documentation was provided. The workshop was divided into 6 sections: 1) Workshop Expectation, 2) Mapping the Current Process, 3) Process Mapping Summary – Current Situation, 4) Areas of Concern/Improvement Opportunities, 5) Mapping the 'Improved' Process, 6) Action plan & Implementing improvements. Below each step of the Kaizen workshop was described:

1. Workshop Expectation. The aim of this section was:

- introduce value stream mapping tool,
- draw a Process Map of the current process,
- identify and prioritise areas of concern/risk,
- identify and prioritise potential improvements opportunities,
- create a Future State Process (improved),
- Incorporate improved process findings into revised cost model.

2. Mapping the 'Current' Process

The company was using Process Mapping as a diagnostic tool that can be used to gather more information about a process and guide the company towards areas of improvement and highlight areas of concern. The process Map was created during the Kaizen workshop and illustrated the product flow through processes, breaking the process down into 6 key areas. The flipchart was also used to record:

- topics that needed additional attention (Concerns/Improvements)
- topics not looked at in detail during the workshop, but also important and should be looked at offline (Parked Issues/Comments).

The flipchart proved to be a valuable tool that helps to capture many important points.

3. Process Mapping Summary – Current Situation

The Current State Map showed that based on standard times the process had required 48 hours and 30 minutes to complete.

4. Areas of Concern/Improvement Opportunities

During this session, the areas of concern and potential improvements were produced. One potential improvement identified during the Kaizen workshop was a requirement for Quality Visual Standards and clear instruction on what is required in regards to quality issues. It was difficult for employees to make a decision (without any references) about whether a component can be sent for remanufacture or rejected. This task was particularly difficult for new or less experienced employees. Some other improvement issues and opportunities were identified:

- Need to clarify all quality issues that make the disassembly operation difficult (e.g. eroded or worn components),
- Need to thoroughly investigate the inspection process and associated documentation,
- Determine a method for robustly assuring that they will be confident that all welds have been checked and repaired,
- Need to define and agree on exact criteria with the customer etc.,
- Need to ensure that core kits are in stock

5. Mapping the 'Improved' Process

The manufacturing team considered the areas of concern and in response produced a 'Future State' Process Map that defined an improved process taking 29 hours 10 minutes to complete.

6. Action plan & Implementing improvements

In regards to improving the process, it was critical to address the identified areas of concern and potential improvements. An Action Plan was created and controlled by management. As well as concentrating on operational functions, it was decided to incorporate other actions assigned to Engineering and Procurement into the Plan.

The Kaizen event and improvement projects identified during that workshop allowed for significant improvements to the process and reduced lead times. The Current State Map highlighted that to remanufacture an item in 23 steps took 48 hours 34 mins (2914 min). The Future State Map showed that only 20 steps and 29 hours and 10 min (1750 min) are needed (a 40% saving). Due to confidentiality agreements investment cost and financial savings haven't been provided. One of the main Kaizen initiative's challenges was a lack of time to implement the improvements because after the workshop employees were busy doing their job.

In addition to the Kaizen workshop, Company A is frequently applying lean practices to make small improvements to overcome or reduce existing problems. Moreover identification and elimination waste have incrementally improved the remanufacturing process within the Company.

***Source of Evidence: Interview & Observations* -** The interview manager said that one of the most beneficial Lean tools is visual management. SQDC boards are placed in a process area to display daily metrics for each category; safety, quality, delivery, and cost. If the teams meet the goals, then the category is marked as green or red if they did not meet it. During the factory tour, it was observed that most of them are marked as green which means that the company is performing well.

***Source of Evidence: Interview, Observations, Company Documentation* -** Before the implementation of lean at Company A, there was a little control over the process and consequently, quality issues were not recorded. The Process Map showed not only the flow of material but also a flow of information, paperwork etc. After developing a VSM, the employees noticed that problems were not where everyone thought they were. Moreover, in the past, the factory didn't have painted floors, and so there was no difference between walkways and work area. As a part of the 5S initiative, a place for everything was defined. The company managed to implement only the first 3S's. Toolboxes were standardised and around 95 % of tools that were required to do the job are there. Next, with each workstation lockable shadow boards with specialist tools for that area were also introduced. The work instructions were also successfully developed although not every eventuality could be covered. Everything that is not identified as a standard operation is called 'incident'. When an incident occurs, the process has to rely mainly on employees' experience. Very often, in that case, the decision is made by more than one employee.

***Source of Evidence: Interview* -** Tools that haven't been implemented within the company (no attempt to implement):

- Overall Equipment Effectiveness,
- Ijdoka, Poka Yoke,
- Single Minute Exchange of Die,
- Kanban,
- Total Productive Maintenance.

Managers claimed that changing the company's culture is one of the most difficult tasks when implementing lean within the Company A. Challenging fixed ideas that have been instilled over the years is not easy. Most people have been working there for more than 30 years. The manager said that although experienced employees are critical of remanufacturing, they can make the application of lean more difficult. Moreover, the variation in condition (how damaged the components are) also makes implementation challenging as well. The manager said: *'in remanufacturing there is always some level of variation that you need to deal with'*. Even though the work instructions are developed, there are still so many things that could be different. The company has attempted to apply one-piece flow but it didn't work. The manager said: '*There are too many bottlenecks'*. Highly variable processing times and stochastic routings of materials cause bottlenecks to shift in the remanufacturing process. The cleaning operation often represents a bottleneck but because the quality of cores varies from unit to unit it might move to a different operation.

Because of the variations in the process and the core supply, Company A has not managed to balance the line. Very often the best and the worst-case scenarios are defined for each core.

5.2.4 Summary

The Lean tools and techniques that have been applied to Company A are listed in Table 5-2.

Table 5-2 Selected Lean tools and principles applied to Company A

Practices	Description	Source of Evidence:
5S	*Pros/Drivers* Company A has applied 5S in certain areas. There are clear examples of Sorting, Setting in order and Systematic cleaning in the plant. *Cons/Obstacles* However, Standardizing and Self-discipline have proved difficult to maintain, even though the company does use daily, weekly and monthly checklists.	Interview, Observation, field notes

Standardised Work Instructions	*Pros/Drivers* Company A has standards for all disassembly processes. The company also reassemble and test using them such that everything is controlled from that perspective. It determines the time required to accomplish each operation as well. Standards have been proven to be a very important tool for the remanufacturing process. *Cons/Obstacles* Even though the introduction of such a tool has been successful, it has been difficult to cover all remanufacturing aspects due to variations inherent to this type of production.	Interview, Observation
Standardisation of kits	*Pros/Drivers* The company introduced the standardisation of remanufacturing kits in terms of the work required to remanufacture as light, medium and heavy.	Interview, Observation
Cross-functional workforce	*Pros/Drivers* Employees at Company A are fully skilled to do any job on the shop floor. This means that they can be easily transferred to another workplace when required to do so.	Interview, Observation, Company documentation
Visual Management	*Pros/Drivers* One of the most successfully implemented toolsets at Company A has been visual management. This tool assists with communication and area configuration.	Observation, interview, field notes
Kaizen Employee Suggestion Program	*Pros/Drivers* The identification and elimination of waste have been a major part of the improvement approach at Company A. All work areas are driven by continuous improvement principles. Teams of employees suggest improvements and ensure that they are implemented in due course. Documents to record and follow up with employee's concerns/improvements were designed and successfully implemented. Gift vouchers are provided to operators for good work/exceptional effort, particularly in terms of continuous improvement. Company A also has an internal chairman's awards process. A Feedback Procedure is also established within this program, and the continuous improvement workshop is the obvious platform for such a process.	Documents from the workshop. Interview
Value Stream Mapping	*Pros/Drivers* Value Stream Mapping (VSM) has been a major focus of Company A and was one of the most valuable tools for the company. By using VSM, Company A was able to visualise the flows (both material and information) of the remanufacturing process, which helped the company to identify and eliminate waste.	Company Documentation, Interview, Case Study notes

A3	*Pros/Drivers* The company is using A3 reports in regards to communicate	Company documentation, Interview
Kaizen Event	*Pros/Drivers* The 5-day workshop was organised in regards to identifying an improvement in a process.	Workshop documentation, Interviews
Cellular Manufacturing	*Pros/Drivers* Remanufacturing of the four major product types (Hydro gas; Final drives; Track Tensioners; Bridging equipment) takes place in focussed areas of the factory. This ensures that the correct tools and necessary process equipment are located at the point of use, which simplifies the remanufacturing process. 5S and Visual Management help to structure the cellular manufacturing efforts at Company A.	Interviews, Observations

5.3 Case Study B

5.3.1 Introduction of Company B

Company B (based in Weston-super-Mare, UK) is one of the largest contracted automotive remanufacturers in the automotive sector across Europe.

Source of Evidence: Interview & Company website - The company was founded in the 1960s (as an industrial metal fabrication company) providing commercial vehicle service and repair. It led to the award of remanufacturing contracts for transmissions, gears, steering, commercial engines and sub-assemblies from Bedford trucks. However, the major remanufacturing development happened in 1978 with a contract from Ford Motor Company. Currently, transmissions (mostly manual, but also some automatic) and engines (both petrol and diesel) are the main products that are remanufactured at the facility. Company B is a contract remanufacturer which currently employs 75 people. The OEM is the supplier of cores and the customer of remanufactured products. The company is using a make-to-order production approach in which remanufacturing starts after the customer's order is received. Furthermore, they work closely with the manufacturing facilities and service divisions to support O.E.M engineers with the failure mode, performance data, and durability. Their commitment to quality is shown by the scope of their accreditations: ISO/TS16949:2002, ISO14001 and

TS16949, FORD Q1, QS9000, ISO9002, ISO14001. Moreover, Company B is regularly assessed by OEMs to confirm that they fulfil all requirements (each OEM has its quality standard that has to be implemented within Company B).

5.3.2 The remanufacturing process within Company B

***Source of Evidence: Interview* -** The remanufacturing process starts with the disassembly of the core into their components. This process is mainly manual and takes (a single employee) around 25 minutes for a manual transmission. To support this process custom-made tools like hydraulic bearing or gear pullers are used. During disassembly, all the compulsory replacement parts like gaskets, bearings and oil seals are removed. Components that can be remanufactured are placed in a custom made carrier trays (made out of metal wires) that have been designed specifically to fit all the components of each model of transmission. Then trays with components are directly transferred to cleaning machines. The five main types of cleaning used to clean the disassembled parts are:

- Vibration cleaning,
- Shot blasting,
- Manual cleaning with brushes,
- Aqueous based chemical cleaning (Submerged and Spray)
- Cleaning using Kerosene (Submerged)

***Source of Evidence: Interview & Observations* -** Sometimes more than one cleaning cycle is required to remove dirt from the components. Once the component is cleaned the inspection is carried out by experienced employees. To support the decision-making process a visual reference was developed by engineers (Figure 5-1).

Visual samples are available to guide inexperienced inspectors or when a new type of product is remanufactured within the facility. The inspection is looking for any worn or deformed gear teeth, mating grooves, keyways or couplings. The shafts are also inspected for bending, other surface irregularities such as straightness, using level gauges.

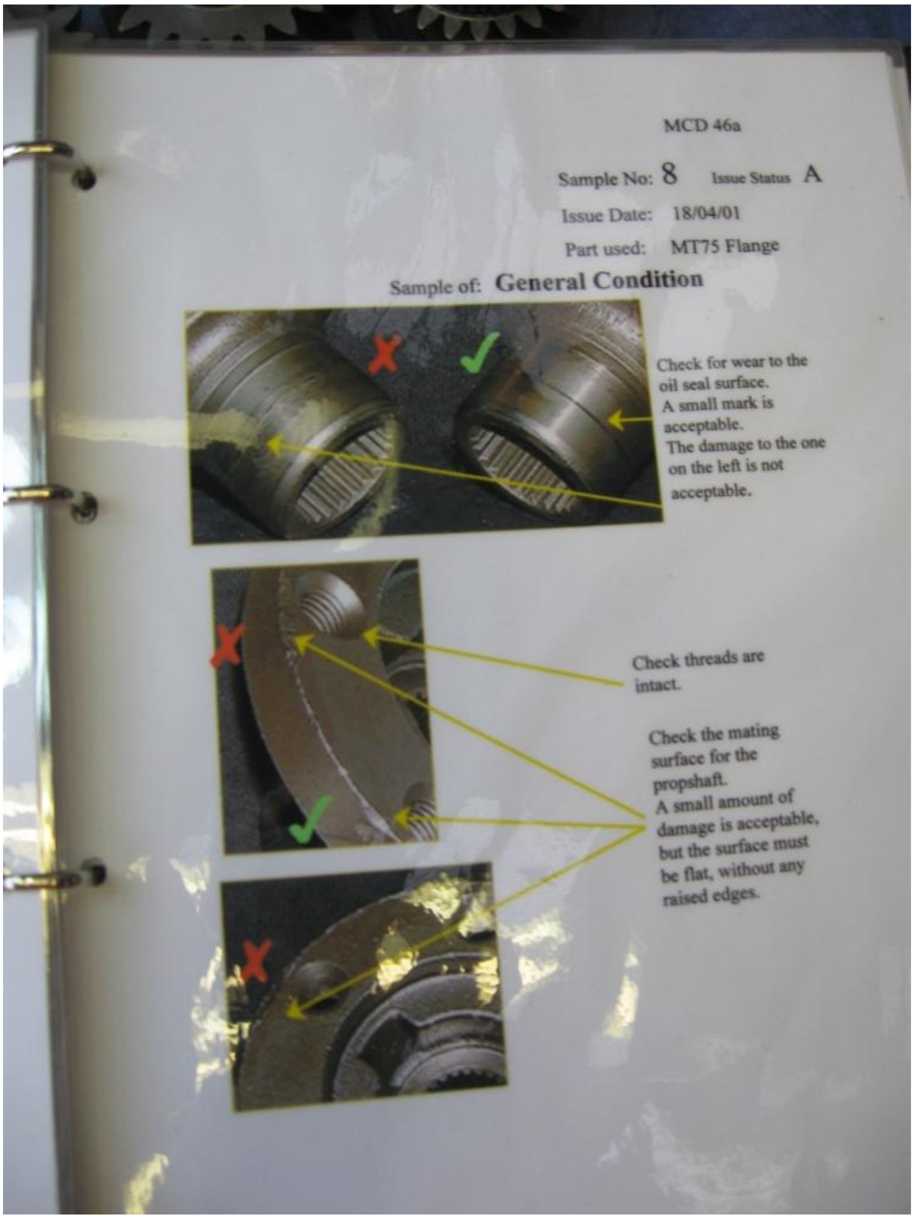

Figure 5-1 Visual inspection references – Company B

***Source of Evidence: Interview & Observations* -** Components that cannot be remanufactured are removed from the process. Because transmissions are placed in containers with a slot designed specifically for each component it is easy to notice which parts have been rejected and need to be replaced with a new one. Containers with all required components are passed to the reassembly area. Cores are then reassembled to their original fit and function and tested (Figure 5-2). The manager interviewed said that the processing time for each operation depends on the product (e.g. type and condition) and people (e.g. experience). The disassembly process is not easy to automate, employees can use tools but not machines and consequently there is a lot of manual work. The Company has twenty thousand units of cores in stock at any time and receives new cores every day. Some of them are in a warehouse for more than 10 years waiting for a customer order. Cores are classified by product type and part number.

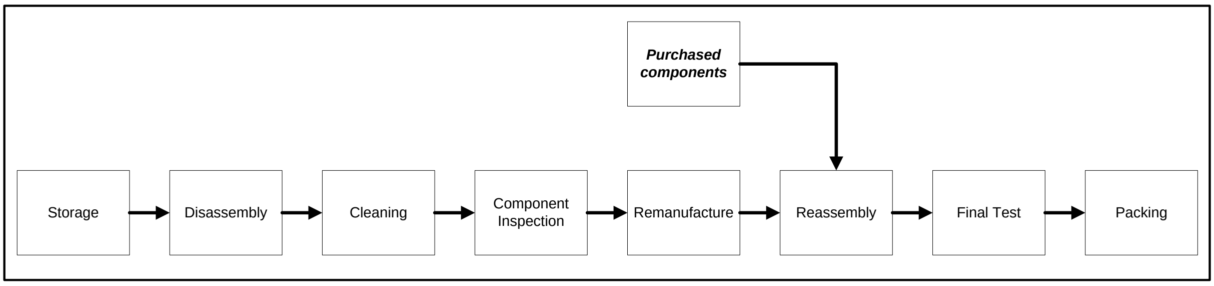

Figure 5-2 Simplified overview of the remanufacturing process: Company B

Source of Evidence: Interview - The business model assures customers (i.e. users) that bringing a broken or worn product to the dealer and in return will receive the remanufactured unit. The dealer sends the returned unit to the original equipment manufacturer (OEM). The OEM Company will send the unit to Company B and collects a remanufactured one to replace the original component. Most of the OEM's carry out their inspection process when they receive cores from a dealer. If the product is damaged the dealer does not receive the full price for that core. As a result, when Company B receives units they are ready to remanufacture. The manager claimed that it is difficult to determine how much work is required to remanufacture a unit before the core is disassembled. It might require no work at all or a completely new insight. The working time required to remanufacture a typical transmission is around 3 hours however the total processing time takes over 2 days. There is a lot of waiting within the process. Because the OEM is obligated (i.e. legal requirements), to have spare parts available 15 years after ending deliveries of components for the series production, Company B doesn't have a problem to get new components. After the remanufacturing process is complete a traceability number is placed on a product. This is done so employees can tell if the unit has already been remanufactured within the facility and to enable traceability of what parts went into the product together with who did it, when they did it and what was the result of the final test. In general for every gearbox taken to the process one remanufactured unit is produced, however occasionally (when there is a shortage of required components), the company strips two gearboxes to make one.

5.3.3 The application of Lean within the Company B

Source of Evidence: Interview & Observations - Company B has started their lean journey when one of their customer's engineers visited the facility and made the first recommendation in regards to improving the process based on lean principles. Subsequently, Company B implemented 5S. Posters were placed both in offices and on the shop floor to increase awareness of the 5S principles (Figure 5-3).

Figure 5-3 5S Poster

Source of Evidence: Interview, Observations - Company B has standardised the way components are handled, the bench layout, workplaces and the tooling that is used. An employee can now move from one work area to another and recognise everything that is there. The employees building gearbox number one will work on a bench with all the tools that he/she needs, likewise if he/she is building gearbox number two he/she will move to another bench and everything will be set up for him/her. Ideally, each bench would be dedicated to a particular product type.

The company is identifying and eliminating the 9 wastes within their processes. This exceeds the seven wastes normally associated with Lean (described in Chapter 2.3.1Common Lean Concepts and Tools) because the company classifies the loss of Talent and Energy (Figure 5-4).

Figure 5-4 9 Waste Poster

Source of Evidence: Interview & Observations **-** Different baskets for different gearboxes had been designed (standardisation of transportation boxes). Company B keep all components, from each gearbox, in a single storage tray. This helps to control the process and they make sure that the same components will be remanufactured. Moreover, it also allows easy identification of what components were removed from the process and have to be replaced with a new one (Figure 5-5, Figure 5-6, Figure 5-7)

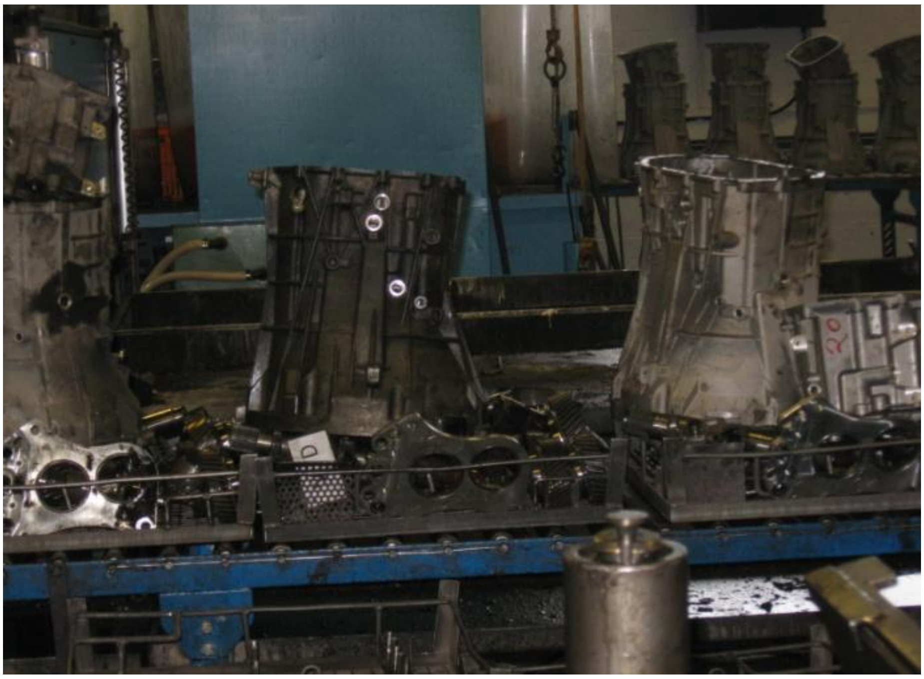

Figure 5-5 Standardisation of transportation boxes (before inspection)

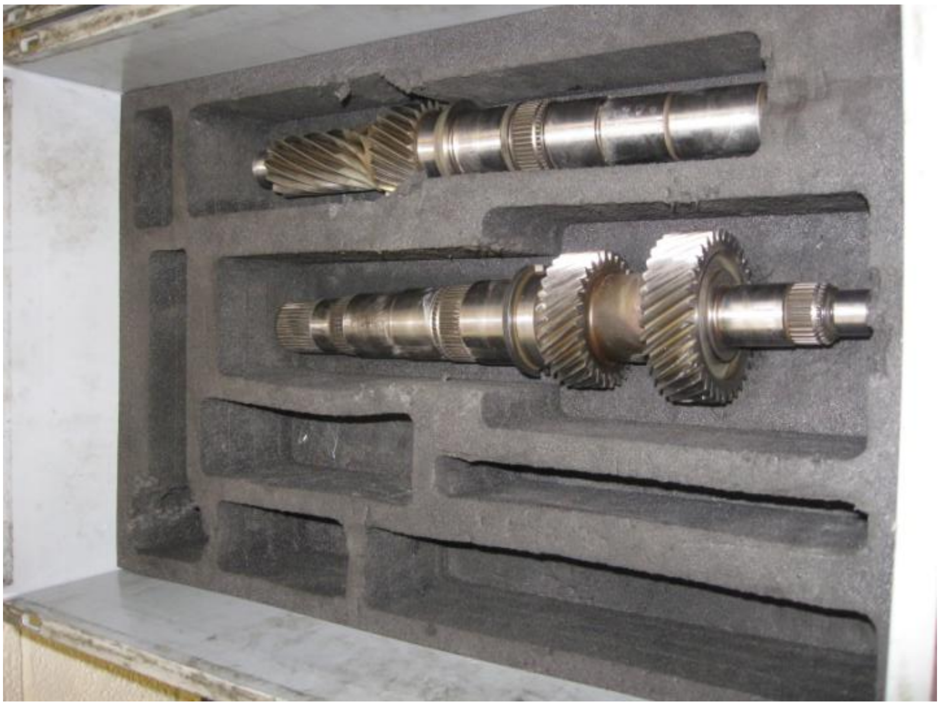

Figure 5-6 Standardisation of transportation boxes (after inspection)

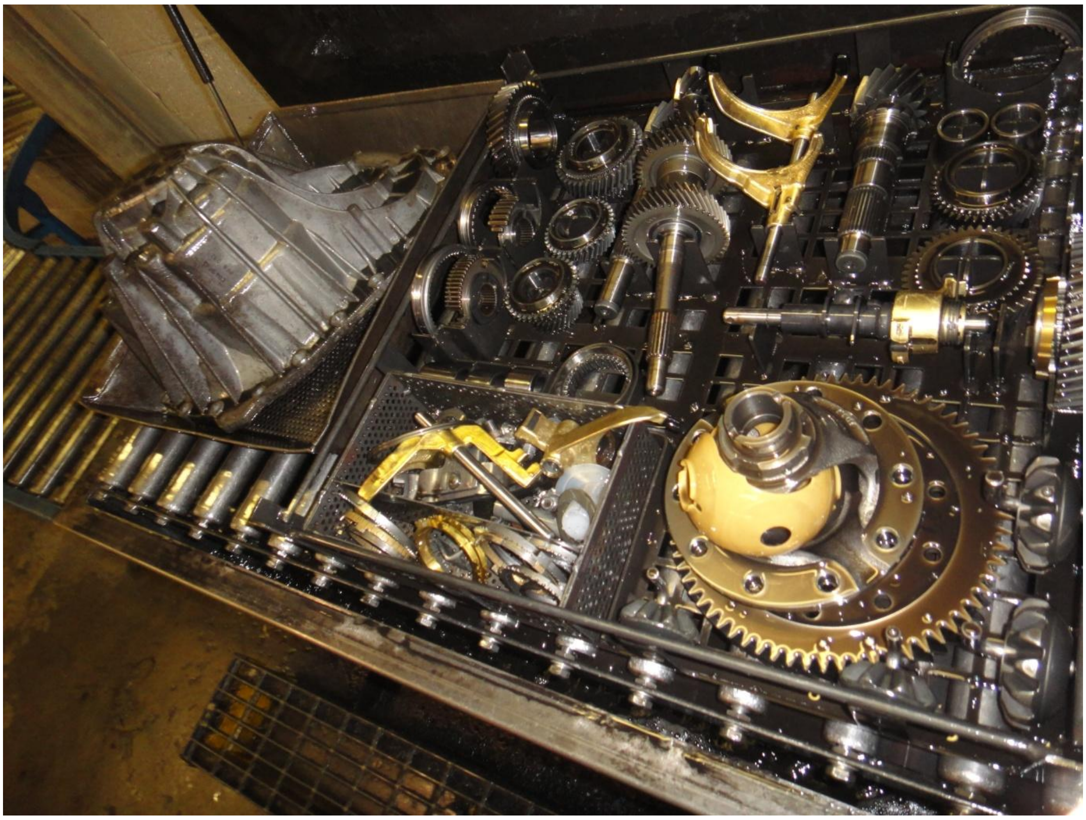

Figure 5-7 Standardisation of transportation boxes

Source of Evidence: Interview, Observations & Company Documentation- Company B has implemented visual management. Key performance indicators are displayed on boards placed on a shop floor (Figure 5-8). Employees have meetings every day to discuss the most important issues that happened over the previous 24hrs. Company B constantly improves the process and develops employee skills to improve their products. All complaints from an internal or external customer must be addressed with the 8D process to ensure that a similar problem will not reoccur. 8-step problem-solving methodology is used in order to find rapid and lasting solutions by a team of employees.

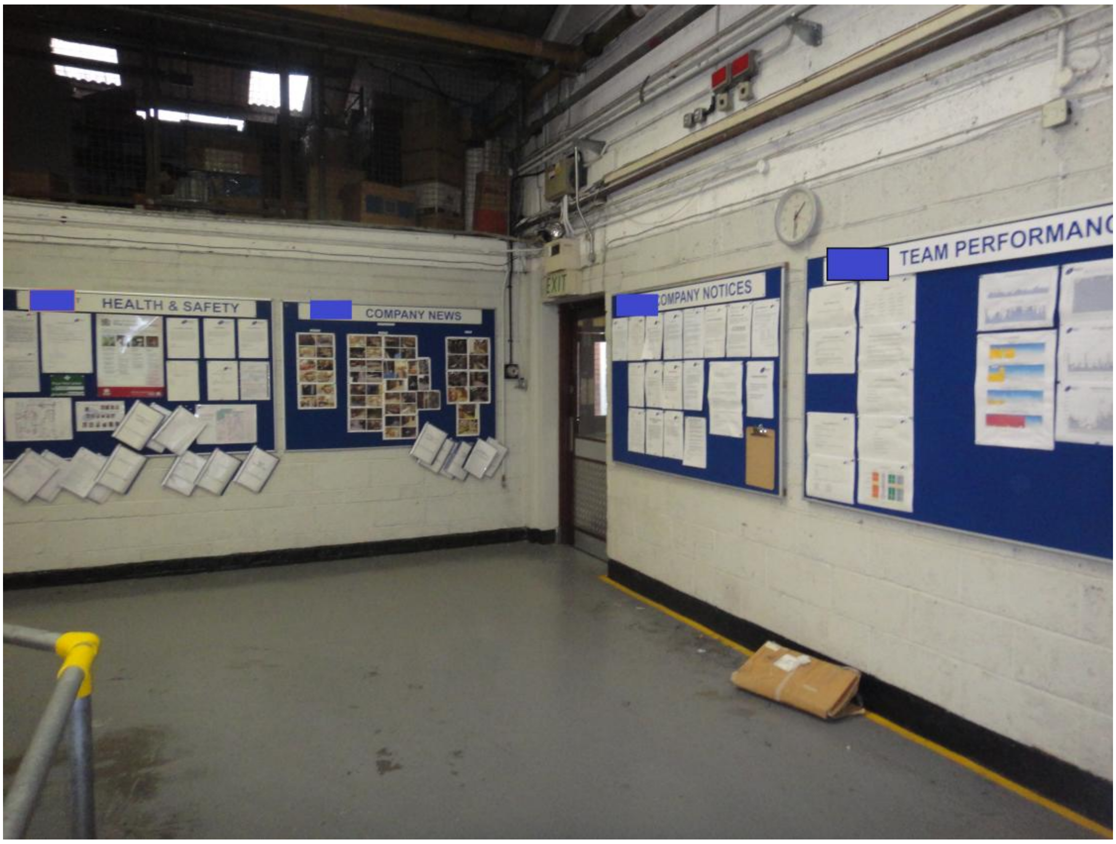

Figure 5-8 Example of Visual Management in Company B

Source of Evidence: Interview- The manager said that Company B hasn't implemented some of the lean tools because the capacity of the facility is higher than the volume of ordered units. Consequently, there is no pressure to initiate improvement activities continuously. Moreover, there was no attempt to apply SMED because each workstation is set up for a particular product and as a result, there are fewer changeovers.

5.3.4 Summary

Table 5-3 represents the lean practices that have been implemented within Company B.

Table 5-3 Selected Lean tools and principles applied to Company B

Practices	Description	Source of Evidence
5S	Company B has applied 5S. Each tool has its place on a workstation and each bench is dedicated to a particular product type. This means that operators can move from one area to another and recognise everything that is there. When any of the tools required to remanufacture a unit are missing it is easy to notice.	Observations, Interview, Researchers Notes
Cross-functional workforce	Company B uses '3 one 3' training which every person can do a minimum of three jobs, and every job can be carried out by at least 3 people. This means that employees receive training to develop skills so that they have the capacity to work across different areas of the factory.	Interview
Kaizen Employee Suggestion Program	Employees can make suggestions for improving the process. These improvements are systematically carried out and followed up by the shop floor teams using PDCA. Employees are rewarded for implemented improvements.	Interview
Transportation Kanban	Company B uses transportation Kanban only for a selected new (replacement) components. Thanks to that the inventory level can be kept low for these components and available when required.	Observations, Interview,
Visual Management	Key performance indicators are displayed on communication boards within the shop floor area. Moreover, the expected results vs. actual performance of cleaning operation are displayed all the time.	Field notes, interview, observations
Standardised Work Instructions	The sequence of movements is standardised and work instructions are displayed at the workstation to support the remanufacturing operations.	Interview, Observations
Standardisation of transportation boxes	Transportation boxes are designed with custom-shaped holes (or compartments) for each component for the different products. Boxes are designed in such a way to ensure that all required components for a specific product can be kept together and allows deviations to be instantly recognised.	Interview, Observations, Photos
Total Productive Maintenance (TPM)	Company B uses TPM to involve the operators in the maintenance of their equipment (Figure 5-9).	Interview, Observations
8D Solving Problem	All complaints from an internal or external customer must be addressed with the 8D process to ensure that similar problem will not reoccur. An 8-step problem-solving methodology is used to find rapid and lasting solutions by a team of employees.	Interview, Observations, Company documentation

Figure 5-9 TPM activities in Company B

5.4 Case Study C

5.4.1 Introduction of Company C

Company C is an OEM remanufacturer based in Wroclaw, Poland. The facility was started in 2011 and Lean methods were introduced in 2013.

Source of Evidence: Interview **-** The main motivation to implement lean within the company was to meet standards set by the group. The main products remanufactured within the facility are compressors and anti-lock braking systems. The company has received a certificate confirming compliance with the requirements of ISO 9001 and ISO/TS 16 949.

5.4.2 The Remanufacturing Process with Company C

The remanufacturing process is divided into two highly dependent subsystems:

(1) The disassembly and remanufacturing area,

(2) The reassembly area.

Source of Evidence: Interview & Observations **-** The remanufacturing process starts with the disassembly of cores. Then some of the components are cleaned to remove the oil and paint. Then the components are sandblasted and cleaned again. Some of the parts go through a machining operation before cleaning. Components are inspected and cleaned up manually if required and reassembled. In the case of end covers, a surface treatment before reassembly is required. This operation is performed outside of the facility (Figure 5-10).

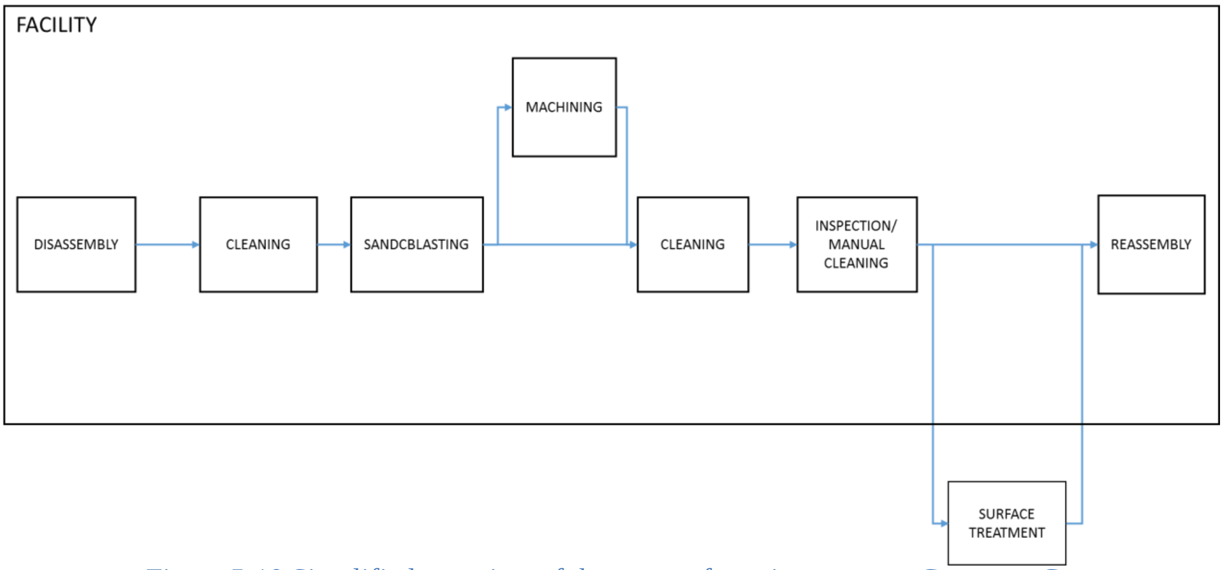

Figure 5-10 Simplified overview of the remanufacturing process: Company C

Source of Evidence: Interview **-** Different problems have been identified by Company C within disassembly, remanufacturing and reassembly areas, consequently different lean tools have been implemented. The interviewed manager claimed that the reassembly area is very similar to conventional manufacturing and most of the lean tools could be implemented straight away. However, it is much more complicated within the disassembly and remanufacturing areas because of the uncertainty of incoming cores. Components with defects that have been detected in the past can be easily assessed as employees already have the required knowledge. However, frequently new types of defects are identified which means that the company has to learn how to deal with them. This is a consequence of the incomplete knowledge that the company has on its product history. Very often cores have been repaired, refurbished or remanufactured in the past, without OEM specification. Very often even after disassembly, it is still difficult to define how many components can be recovered. That makes production planning more difficult. Moreover, the time required to remanufacture each component might be different depending on the quality of the core.

The manager gave a few examples from the past few weeks that highlighted everyday problems that the company has to deal with: There is one component that, according to the specification, should have unpainted surface. Recently, a whole batch of components was delivered where the paint had been applied to various elements. Consequently, engineers had to identify how to remove this paint from components and then a planning specialist had to add extra time to the remanufacturing process to make sure that the quality of the components will be 'as good as new'. As a result, the efficiency of the remanufacturing process decreased. Usually, remanufacturing of this type of component is postponed for a few days until an extra shift is organised. As a result, FIFO within the disassembly and remanufacturing area are not achieved. Moreover, to fulfil customer demand, the production planner has to take into consideration the salvage rate of components. For example, if the customer requires 100 units per hour and the average loss caused by the quality of incoming components is 30%. It means that 130 units have to enter the process to make sure that each customer receives a product on time.

Uncertainty in quality is not the only problem that the company is facing. The stock is growing fast as the company is forced to take all cores that are available on the basis that they might be useful in the future. Normally, the only opportunity to obtain a used product (i.e. a core) is when the customer doesn't want that item any longer not when the remanufacture process/customer needs it.

5.4.3 The application of Lean within Company C

Source of Evidence: Interview & Observations - It was highlighted that the information required during the remanufacturing process changes very quickly. Therefore, apart from experienced employees, a system of communicating and sharing information was required for the other staff. For example, if an employee is not sure about the quality of the component, he or she leaves that component in a special area with a yellow card attached as a signal for an engineer to inspect that component.

Source of Evidence: Interview & Company Documentation - For remanufacturing operations dealing with large variations in product (like Company C), it was identified that a cross-functional workforce was critical to balancing capacity with a highly variable processing time, consequently to increase flexibility the company has implemented a skills matrix that includes all operations of the process and a list of operators who can perform those operations. This helps shift managers and leaders to move the right employee to the right tasks when required.

Source of Evidence: Interview, Company Documentation & Observations - Hourly production boards were introduced to provide production results compared to plan hour by hour. This creates a feedback system for estimated processes that allows problems to be identified in real-time and better utilise capacities.

Source of Evidence: Interview - The interviewed manager confirmed that changes to the factory layout brought a lot of benefits as it allowed optimization of the shop floor according to the flow of the product families. Before this, it was often difficult to identify where the components should go from one operation to another. Moreover, the distance that each product had to travel to pass through all remanufacturing operations was shortened.

The manager confirmed that the implementation of new solutions within the facility is easier because of employee engagement. There are a lot of new employees without 'old habits' that is why resistance to change is not an issue during the application of lean tools and practices within this facility.

It was observed that some of the lean tools have been adjusted to fit the remanufacturing environment. For example when determining Cycle Time, in addition to normal variation in work content operator skills and machine cycle time, the variation in the quality of incoming cores has to be taken into consideration. To control the supply chain in the remanufacturing area, company C is planning to adjust and implement a Production Kanban. Currently, components are ‘pushed’ from one workstation to another in batches. This results in high inventory located before the reassembly area. It is difficult to introduce a pull system as the remanufacturing process is not stable. The company is not capable of remanufacturing consistent results over time because components often have to be removed from the process when they do not fulfil the required specification. That is why, when establishing the number of Kanban that will fulfil customer demand, an extra Kanban will be located in the process. One of the barriers indicated by the manager to the successful application of lean within the facility is the lack of time required to work on new solutions. Solving daily problems has a higher priority than work that has to be done in regards to adopting existing lean solutions to the remanufacturing.

Figure 5-11 5S and Standard Work Instructions within Company C

5.4.4 Summary

Table 5-4 represents the lean practices that have been implemented in Company C.

Table 5-4 Selected Lean tools and principles applied to Company C

Practices	Description	Source of Evidence
Kaizen Employee Suggestion Program	Applied within the whole remanufacturing process – Suggestion system within the company engages employees to generate ideas for improvement. Once per quarter the ideas are assessed by managers and employees are rewarded.	Interview, Kaizen Board that represents the state before and after Kaizen
5S	Applied within the whole remanufacturing process – The place for everything is defined (Figure 5-11). To sustain the 5S program within a facility, audits are performed (each week one of the areas is inspected). Currently, the aim is 90%. After the audit, the 'owner' of the area is obligated to fix everything that was pointed out during the audit.	5S Audits sheet, Audits Plan, Observation, Interview

Total Productive Maintenance (TPM)	Applied within the whole remanufacturing process – Operators before they will start to work they are obligated to investigate (according to the checklist) if the machine is working properly (there is no leakage etc). Moreover, preventive maintenance is scheduled and performed by the Maintenance Department.	Interview, Company documentation, Checklist with employees signatures that confirm inspection of the equipment
Cross-functional workforce	Applied within the whole remanufacturing process- Employees are trained to work on more than one workstation. Every two hours the rotation among different workstation is planned. The skills matrix is regularly reviewed and updated.	Interview, Observation, Skills Matrix table
Production Kanban	Applied within the reassembly area – The signal is used to give permission to take material from warehouse to reassembly unit.	Interview, Kanban Cards
Cycle Time	Applied within the reassembly area– Cycle time is defined within the reassembly area. It is more difficult in regards to disassembly and remanufacturing area as except normal variation in work content operator skills and machine cycle time, variation in the quality of incoming cores exist	Interview
Standard of dealing with faulty parts	Applied within the whole remanufacturing process – If the employee is not sure about the quality of the component, he or she leaves that component in a special area with a yellow card attached. It is a signal for the engineers to inspect that component.	Interview, Observations
Standardised Work Instructions	Applied within the whole remanufacturing process – Work Instructions are applied within each workstation and contain information about all steps required to complete work on each workstation (Figure 5-11). Moreover, it includes acceptability criteria for components to support the decision-making process (Figure 5-12).	Interview, Observations, Company documentation
Production Analysis Board	Applied within the whole remanufacturing - These are placed nearby machines and workplaces and they show how the output looks like in regards to the plan from hour to hour. If the plan is not achieved the reason for that need to be written down. The hourly board is a visualization of the problems at the shop floor level.	Interview
Problem Solving	Applied within the whole remanufacturing process – If a problem was identified within the process, the root cause analysis has to be done. To make sure that it will not happen again the countermeasures are defined and applied. QRQC, 5W1H, Ishikawa Diagram are mainly used.	Company documentation, Interview, QRQC form with 5W1H and Ishikawa Diagram

FIFO	Applied within the reassembly area – The date of arrival is determined and the employees take the oldest one for the further process. Because the inventory between some of the workstations is high, the easy spreadsheet application was developed to show which item employee should take to keep FIFO. Moreover, each unit, no matter the quality, has to go through each operation to be remanufactured.	Interview
Visual Management	Applied within the whole remanufacturing process- To ensure that the work is done in the right way and at the right time, every day, leaders, engineers and the shift managers have a meeting in front of the area board to discuss performance, quality, safety and the main problems that occurred in the last 24 hours. Similar routines also function at a higher level of management. Key performance indicators are displayed on a board.	Interview, Daily Routine Management Board
Cellular Manufacturing	Applied with the whole remanufacturing process Successfully implemented. Products flow through the cell in small lots	Interview, Observations

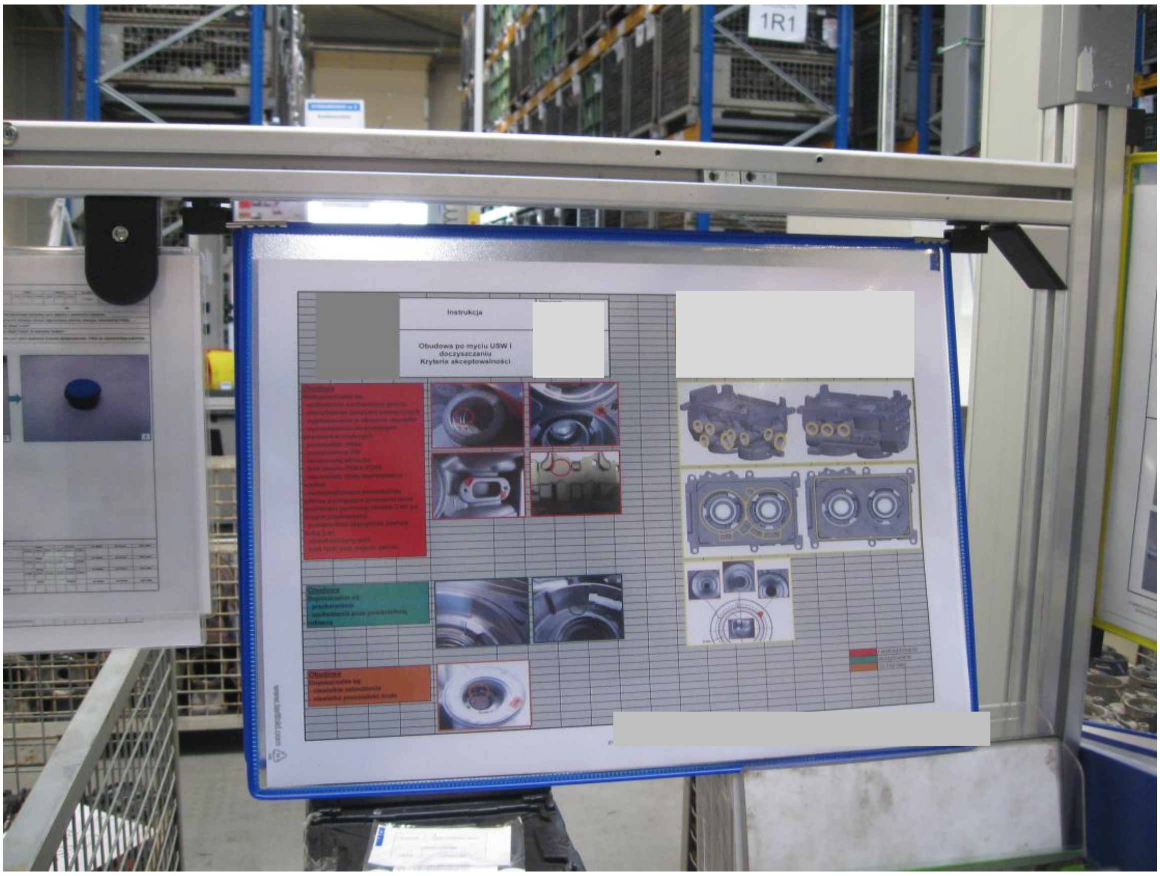

Figure 5-12 Work Instructions

5.5 Cross-Case Study

Observations from the case studies were discussed in the previous chapter separately, without reference to each other. The purpose of the cross-case study is a further analysis of collected data according to the diagram below (Figure 5-13) in regards to:

1. compare the data from all case studies to see if information obtained is consistent and so identify patterns in the responses,
2. identify how the application of lean practices reduce the impact of the complexity of production planning and control in the remanufacturing processes identified by Guide Jr, (2000)
3. identify how the complexity of the remanufacturing process limits the application of lean practices.

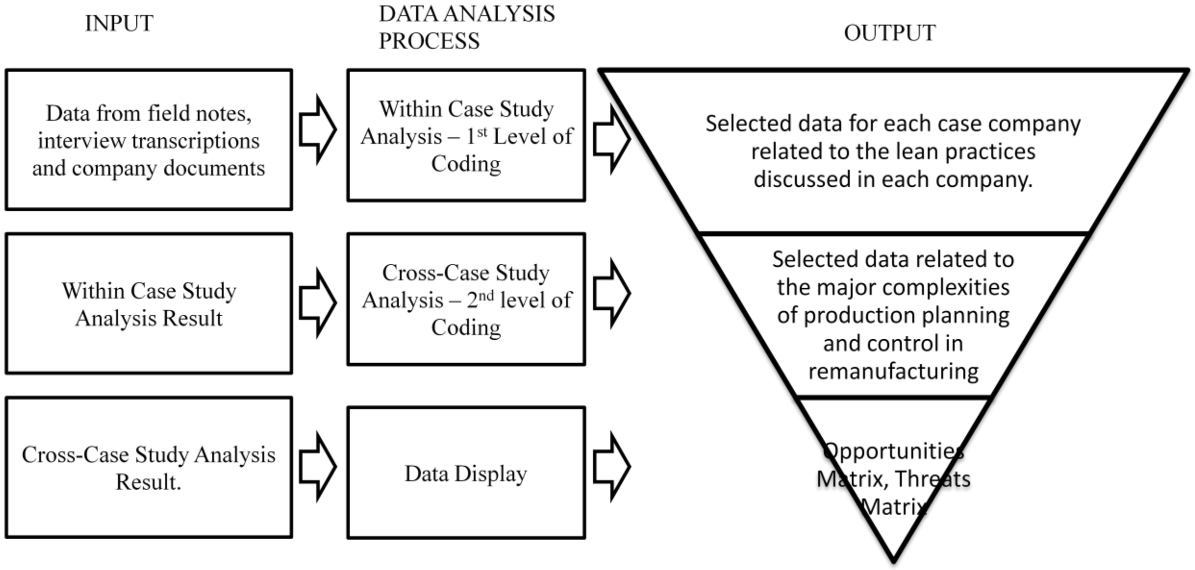

Figure 5-13 Data Analysis Process

5.5.1 Comparison of data from all case studies

Table 5-5 represents a summary of the data collected during the interviews, observations, and review of documentation.

Table 5-5 Successful application of lean tools and practices within Case Companies

Lean tools and practices	Case Companies	Source of Evidence
5S	**Company A:** Company A has applied 5S in certain areas. There are clear examples of Sorting, Setting in order and Systematic cleaning in the plant. However, Standardizing and Self-discipline have proved difficult to maintain, even though the company does use daily, weekly and monthly checklists. **Company B:** Company B has applied 5S. Each tool has its place on a workstation and each bench is dedicated to a particular product type this means that operators can move from one area to another and recognise everything that is there. When any of the tools required to remanufacture a unit are missing it is easy to notice. **Company C:** The place for everything is defined. To sustain the 5S program within a facility, audits are performed (each week one of the areas is inspected). Currently, the aim is 90%. After the audit, the 'owner' of the area is obliged to fix everything that was pointed out during the audit.	Interview, Observation, field notes, 5S Audits sheet, Audits Plan
Visual Management	**Company A:** One of the most successfully implemented toolsets at Company A has been visual management. This tool assists with communication and area configuration. **Company B:** Key performance indicators are displayed on communication boards within the shop floor area. Moreover, the expected results vs. actual performance of cleaning operation are displayed all the time. **Company C:** Key performance indicators are displayed on boards. Every day, leaders, engineers, and the shift managers meet in front of the area board to discuss performance, quality, safety and the main problems that occurred in the last 24 hours.	Observation, interview, field notes, Daily Routine Management Board
Standardised Work Instructions	**Company A:** Company A has standards for all disassembly processes. The company also reassemble and test using them such that everything is controlled from that perspective. However, it is difficult to determine the time required to accomplish each operation. Standards have been proven to be a very important tool for the remanufacturing process. Even though the introduction of such a tool has been successful, it has been difficult to cover all remanufacturing aspects due to variations inherent to this type of production. **Company B:** The sequence of movements is standardised and work instructions are displayed at the workstation to support the remanufacturing operations. **Company C:** Work Instructions are applied within each workstation and contain information about all steps required to complete work on each workstation. Moreover, it includes acceptability criteria for components to support the decision-making process.	Interview, Observation Company documentation
Kaizen Employee Suggestion Program	**Company A:** The identification and elimination of waste have been a major part of the improvement approach at Company A. All work areas are driven by continuous improvement principles. Teams of employees suggest improvements and ensure that they are implemented in due course. Documents to record and follow up with employee's concerns/improvements were designed and successfully implemented.	Documents from the workshop, Interview Kaizen Board that represents the state before and

		Gift vouchers are provided to operators for good work/exceptional effort, particularly in terms of continuous improvement. Company A also has an internal chairman's awards process. A Feedback Procedure is also established within this program, and the continuous improvement workshop is the obvious platform for such a process. **Company B**: Employees can make suggestions for improving the process. These improvements are systematically carried out and followed up by the shop floor teams using PDCA. Employees are rewarded for implemented improvements. **Company C:** Suggestion system within the company engages employees to generate ideas for improvement. Once per quarter the ideas are assessed by managers and employees are rewarded.	after Kaizen
Standardization	Standardisation of kits	**Company A:** The company introduced the standardisation of remanufacturing kits in terms of the work required to remanufacture as light, medium and heavy.	Interview, Observation
	Standardisation of transportation boxes	**Company B**: Transportation boxes are designed with custom-shaped holes (or compartments) for each component for the different products. Boxes are designed in such a way to ensure that all required components for a specific product can be kept together and allows deviations to be instantly recognised.	Interview, Observations, Photos
	Standard of dealing with faulty parts	**Company C:** If the employee is not sure about the quality of the component, he or she leaves that component in a special area with a yellow card attached. It is a signal for the engineers to inspect that component.	Interview, Observations
Cross-functional workforce		**Company A:** Employees in Company A are fully skilled to do any job on the shop floor. This means that they can be easily transferred to another workplace when required to do so. **Company B:** Company B uses '3 one 3' training which is every person can do a minimum of three jobs, and every job can be carried out by at least 3 people. This means that employees receive training to develop skills so that they have the capacity to work across different areas of the factory. **Company C:** Employees are trained to work on more than one workstation. Every two hours the rotation among different workstation is planned. The skills matrix is regularly reviewed and updated.	Interview, Observation, Company documentation, Skills Matrix table
Value Stream Mapping		**Company A:** Value Stream Mapping (VSM) has been a major focus at Company A and was one of the tools most valued by the company. By using VSM, Company A was able to visualise the flows (both material and information) of the remanufacturing process, which helped the company to identify and eliminate waste.	Company Documentation, Interview, Case Study notes
Kanban		**Company B:** Company B uses a transportation Kanban only for a selected new (replacement) component. Thanks to that the inventory level can be kept low for these components and available when required. **Company C:** The signal is used to give permission to transport material from the warehouse to the reassembly area.	Observations, Interview, Kanban Cards

Total Productive Maintenance (TPM)	**Company B:** Company B uses TPM to involve the operators in the maintenance of their equipment. **Company C:** Before an operator starts work they are obligated to investigate (according to the checklist) if the machine is working properly (there is no leakage etc). Moreover, preventive maintenance is scheduled and performed by the Maintenance Department.	Interview, Observations Company documentation, Checklist with employees signatures that confirm inspection of the equipment
Problem Solving	**Company A:** Company is using A3 reports in regards to communicate **Company B:** All complaints from an internal or external customer must be addressed with the 8D process to ensure that a similar problem will not reoccur. An 8-step problem-solving methodology is used to find rapid and lasting solutions by a team of employees. **Company C**: If a problem was identified within the process, the root cause analysis has to be done. To make sure that it will not happen again the countermeasures are defined and applied. QRQC, 5W1H, Ishikawa Diagram are mainly used.	Company documentation, Interview, Observations, QRQC template with 5W1H and Ishikawa Diagram
Kaizen Event	**Company A:** 5 days workshop was organised in regards to identifying an improvement in a process.	Workshop documentation, Interviews
Cycle Time	**Company C:** Cycle time is defined within the reassembly area. It is more difficult in regards to disassembly and remanufacturing area as except normal variation in work content operator skills and machine cycle time, variation in the quality of incoming cores exist	Interview
Production Analysis Board	**Company C:** These are placed nearby machines and workplaces and they show how the output looks regarding the plan from hour to hour. If the plan is not achieved the reason for that needs to be written down. The hourly board is a visualization of the problems at the shop floor level.	Interview
FIFO	**Company C:** Applied only within the reassembly area. The date of arrival is determined and the employees take the oldest one for the further process. Because the inventory between some of the workstations is high, the easy spreadsheet application was developed to show which item employee should take to retain FIFO.	Interview
Cellular Manufacturing	**Company A:** Remanufacturing of the four major product types (Hydrogas; Final drives; Track Tensioners; Bridging equipment) takes place in focussed areas of the factory. This ensures that the correct tools and necessary process equipment are located at the point of use, which simplifies the remanufacturing process. 5S and Visual Management help to structure the cellular manufacturing efforts at Company A. **Company C:** Successfully implemented. Products flow through the cell in small lots	Interviews, Observations

The data collected within case companies were compared with each other. However, not all the case companies implemented the same lean tools. As has already been highlighted (Chapter Literature Review) Lean provides tools which need to be chosen according to the goals that the company is trying to achieve or the problems it is trying to solve. Consequently, companies do not always apply the same lean tools in a similar order. It depends on the problems that they are facing and the maturity of a lean culture in those firms. However, the greater frequency of usage of particular lean practice, confirms the success of that application in the remanufacturing environment (Table 5-6).

Table 5-6 Application Lean Practices within Case Companies.

Lean Practice \ Company	Company A	Company B	Company C	Summary
5S	X	X	X	3
Kaizen Employee Suggestion Program/Kaizen Event	X	X	X	3
Standard Work Instructions	X	X	X	3
Visual Management	X	X	X	3
A3/8D/ Problem Solving	X	X	X	3
Standardization	X	X	X	3
Cross-functional workforce	X		X	2
Transportation / Production Kanban		X	X	2
Cellular Manufacturing	X		X	2
Cross-functional workforce		X		1
TPM			X	1
Cycle Time (within the reassembly area)			X	1
Value Stream Mapping	X			1
Total Productive Maintenance (TPM)		X		1
Production Analysis Board			X	1
FIFO (within the reassembly area)			X	1

Visiting 3 case companies allowed a broad understanding of how lean tools are used in the remanufacturing environment.

The case study research used multiple sources of evidence to capture the complex reality under investigation. Table 5-7 shows the main sources of evidence informing the findings.

Table 5-7 Sources of evidence for findings

Source of Evidence	The number of pages used in the analysis
Interview – transcribed	107 pages double-spaced
Direct Observation – field notes, pictures	94 pages double-spaced
Documentation – company-related documents	20 pages

5.5.2 Identifying how the application of lean practices reduces the impact of the complexity of production planning and control in the remanufacturing processes

It was identified that not the same lean tools were implemented in each case company because each company was choosing them according to the goals that were trying to achieve or the problems trying to solve.

Table 5-8 presents lean practices (used by Case Companies) that respond to the particular complexity of production planning and control in remanufacturing identified by (Guide Jr, Jayaraman and Srivastava, 1999).

Table 5-8 Lean practices (used by Case Companies) that respond to the particular complexity of production planning and control in remanufacturing identified

		The complexity of production planning and control in remanufacturing				
		Disassembly of returned products	The complication of material matching restrictions	Uncertainty in materials recovered from returned items	Highly variable processing time	Stochastic routings for material for remanufacturing operations
Lean Practices	Standardised work instructions	x			x	
	Standardisation(of transportation boxes and kits)		x		x	
	Kanban			x		
	Cross-functional workforce				x	
	Production Analysis Board				x	
	5S					x
	Visual Management				x	
	Cellular Manufacturing				x	
	Total Production Maintenance					x

Below there is a list of lean tools that were implemented by Case Companies resulting in relieving the negative effects of complexity of production planning and control in remanufacturing identified by Guide.

Standardised Work Instructions – All of the Case Companies have implemented Standardised Work Instructions. Interviewed managers have confirmed the application of that practice has a positive influence on the disassembly of returned products even though it has been difficult to cover all aspects due to variations inherent to this type of production. All of the Case Companies had confirmed that disassembly of the used product is difficult as it requires knowledge on how to deal (e.g. grip, clean, remove etc) with components of unknown quality. Managers in all case companies highlighted that before introducing Standardised Work Instructions each employee had his/her technique of how to perform this operation and only more experienced employees had the knowledge of how to disassemble parts without damaging them, thus reducing scrap etc. The Manager in Company A added that very often less experienced employees didn't know, for example, when to use a penetrating lubricant (to make disassembly easier) and consequently they were disassembling not using any oil. Often, parts were broken by the excessive torques applied. This resulted in a longer than required disassembly process which also used more effort. Furthermore, managers have confirmed that the introduction of Standardised Work Instructions allowed to release internal process variation introduced by the worker.

Standardisation-

- **Standardisation of transportation boxes –** Considering of customer requirements**,** Company B has to reassemble the same components that were disassembled. The interviewed manager highlighted that having a few cores or even more at the same time within the process, makes it difficult to fulfil that requirement. To address that issue Company B kept all components in one basket with specifically-designed spaces for each component of the product (Figure 5-14). Boxes are designed in such a way to ensure that all required components for a specific product can be kept together. Moreover, any deviations can be instantly recognised. When any component was removed from the process it can be quickly recorded.

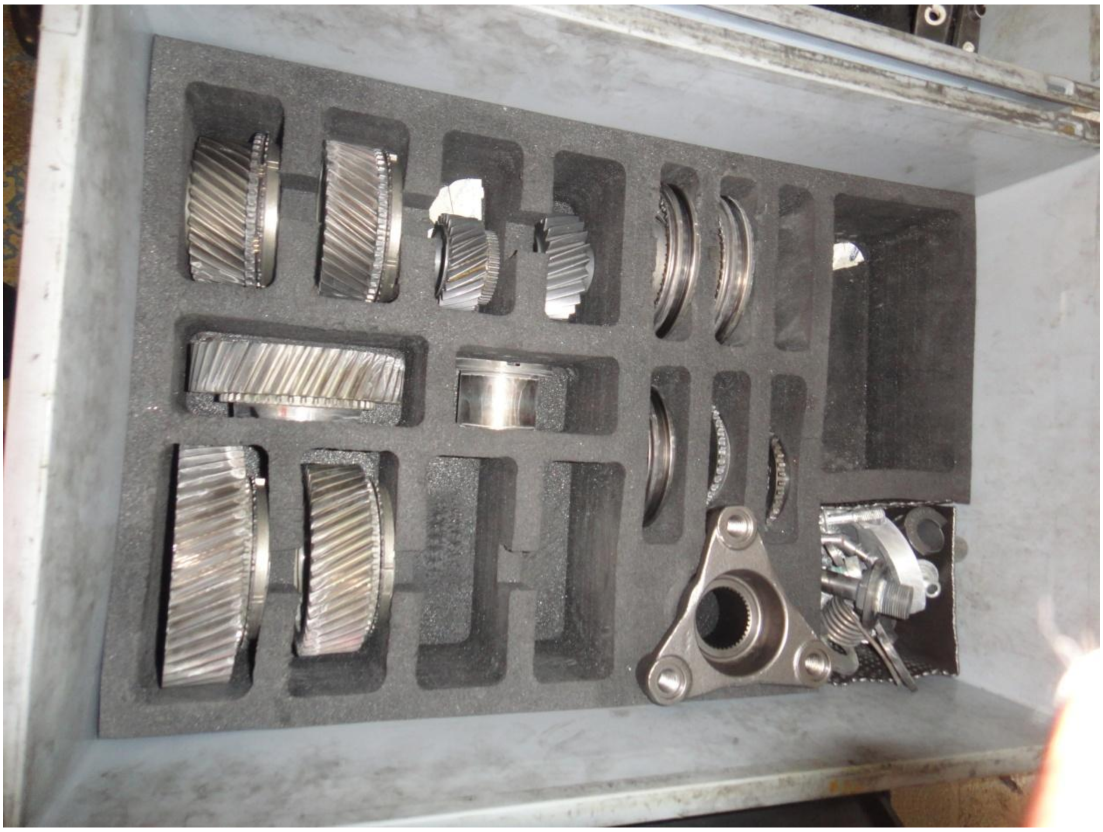
Figure 5-14 Standardisation of transportation boxes

- **Standardisation of Kits** – Company A has implemented the Standardisation of Kits. It was highlighted that before the application of Standardisation of Kit it was difficult to plan the remanufacturing process because of uncertainties of incoming cores. Depending on the quality of the product the time required to remanufacture was different. The standards in terms of the work required to remanufacture were defined as light, medium and heavy. For each type of kit, the time and effort that is required to remanufacture were also established. From now on each product is inspected by engineers to classify them as a medium, light or heavy kit. Employees reported that introducing the standardisation of kits helped to better plan capacity and to reduce levels of uncertainty involved with the different conditions of products and components that are arriving at the facility. Currently planning specialists can more precisely plan the remanufacturing process.

Kanban – It was confirmed that Transportation Kanban was implemented (within Company B and Company C) in response to the problem with purchasing new components that are required to remanufacture units. Managers have admitted that, because of the uncertainty in the materials recovered from returned items, it was difficult to predict how many new components will be required to remanufacture a particular number of units. This meant that the consumption of new components was constantly observed to ensure their availability. The Production Manager in Company C said that in conventional manufacturing, it is much easier to calculate what will be required to manufacture products, as when the company is planning to produce, for example, 1000 pcs., the same amounts of components have to be ordered. The safety stock for each component has been defined based on the time required to buy new parts. When the stock is below the safety level, it is a signal for the purchasing specialist to order new components. This system assures that safety stock is always available (not excessive stock). The interviewed Managers said that the application of Transportation Kanban made employees' life easier as they don't have to keep track of how many components were used every day. From now on, the order is made based on the need for the remanufacturing process. During the interview, it was also noted that because of the high variability of products not all spare components can be kept in a stock and some of them have to be ordered when they are needed for production.

Cross-functional workforce – All of the case companies implemented Cross-functional workforce. Interviewed Managers have highlighted that it is critical to have multi-skilled employees to account for the uncertainty involved in highly variable processing times. Very often parts need more time and effort to be remanufactured than was anticipated during the planning stage. In response to this issue companies train their workers so almost every employee can work on each workstation and in result he/she can support any operation when required. Implementing a skills matrix, enable supervisors to visually recognise which employee has required competencies to support the particular operation.

Total Productive Maintenance – This practice has been implemented within Company B and Company C. Instructions on how to perform cleaning and checks on particular machines have been developed. Each week dedicated employees perform activities according to these instructions. Interviewed employees in both companies admitted that TPM assures that remanufacturing equipment is available whenever cores arrive at the facility. It is a way of increasing the reliability of production machinery.

Production Analysis Boards – Company C has implemented Production Analysis Boards. Interviewed Manager and Engineer have confirmed that the introduction of this tool helped to observe the process which made all the problems visible immediately. Boards, with a production plan, were placed nearby the production workstation. In case the workstation did not accomplish the plan, the leader/employee needs to write down the cause. It was highlighted that because in remanufacturing new problems involving the quality of incoming cores show up constantly it is very important to be able to identify them quickly to solve them. Every few hours, or at least once during a shift, the production manager together with the engineer analyzes identified problems. The knowledge is important for the planning specialist who can note that the time required to remanufacture this type of defect might be longer. Before the boards have been implemented if, for example, oil was found on the component (a new problem that the company had not had to deal with previously) and the standard process of cleaning hadn't removed oil from the core, the employee had to clean this component again. As a consequence, the remanufactured product hadn't been shipped on time because the planning specialist didn't take into consideration the extra time required for cleaning. From the time the hourly production boards have been introduced, it shows clearer if the plan hasn't been accomplished and allowed employees to record the reason for the situation (in this case plan couldn't be accomplished because one component had to be cleaned twice). This is a signal for engineers that oil cannot be removed during a standard cleaning. In result, countermeasures are quickly implemented and standards updated. In the future when this defect occurs employees are trained to use different cleaning liquid, reducing the uncertainties involved with that defect. Thus, planning becomes more easy and accurate when similar cores arrive in the future. Interviewed Managers reported that without a tool like hourly production boards, a planning specialist didn't know why the plan has not been achieved, and the next time when a core with a similar defect arrived at the facility, the plan was again inaccurate.

Five S (5S) – All of the Case Companies have implemented 5S within their facilities. Interviewed Managers confirmed that before the application of the practice, the workstations were not organised properly and very often tools were missing and employees were wasting their time looking for them. It was highlighted that the application of 5S allowed for an organised workspace in a way that when extra operations are required, time is not wasted for looking for tools that are needed. Particularly it is important in remanufacturing where many uncertainties exist. The companies regularly reviewed the compliance of the 5S standards. After each Audit, the tasks for particular employees are defined.

Visual Management – All of the Case Companies are using communication boards. They display performance status and communicate problems. Moreover, team leaders together with the shift leader and representatives from other departments meet regularly to discuss any deviations that occurred within the process. Very often these deviations are caused by the uncertainties involved with the quality of incoming cores. Interviewed employees have confirmed that the identification of such abnormalities is critical in improving the process. Solving identified problems ensures that the processing time is more stable. It was also said that even though the problem cannot be solved straight away, the process can be better planned taking into consideration the identified issues and their requirements. One case company gave an example of the effective use of Visual Control Boards. The Manager said that during one of the meetings they noticed that the productivity of the process significantly decreased within the past few weeks. The result of the analysis showed that cores that have arrived in the last delivery were significantly covered by rust (probably stored outside). Employees had to spend extra time removing that damage. The QRQC, 5W1H and Ishikawa Diagram was used to analyze that problem. The countermeasures were taken. It was highlighted that because of the uncertainties associated with the quality of incoming cores that influenced the processing time, the information flow is therefore critical.

Cellular Manufacturing – Company A and Company C implemented Cellular Manufacturing. In conventional manufacturing depending on the production volume, several employees can work within the cell to fulfil the customer demand. It was noticed that it is similar in a remanufacturing environment. Depending on the time required to complete work (the result of the quality of the incoming product) several people can work within the cell. In both companies, each component has to go through each operation, regardless of the quality of the unit.

5.5.3 Identifying how the complexity of the remanufacturing process limits the application of lean practices

Below we discuss only tools for which the implementation was limited within Case Companies by the complexity of the remanufacturing process identified by Guide Jr (2000). Only tools which were attempted to be implemented, was discussed. Lack of effort does not prove that a particular tool cannot be successfully used in the remanufacturing process. Table 5-9 represents lean tools that the implementation of which was limited by the complexity of production planning and control in remanufacturing.

Table 5-9 Lean tools the implementation of which was limited by the complexity of production planning and control in remanufacturing

		The complexity of production planning and control in remanufacturing			
		Stochastic routings for material for remanufacturing operations	Uncertainty in materials recovered from returned items	Highly variable processing time	The complication of material matching restrictions
Lean Practices	First In First Out (FIFO)	x			x
	Standardised Work Instructions	x	x	x	
	Transportation Kanban		x		
	Production Kanban		x		
	Cellular Manufacturing	x			

First In First Out (FIFO) – Managers from Company A and B said that stochastic routing for material made the application of FIFO very challenging. Within Company A and Company B, similar components have to go through different operations depending on the quality. As a result, parts/units often leave the process in a different sequence to which they have entered. Only Company C has to implement FIFO (within the reassembly area) as all components have to go through the same operations. Company C has started to implement FIFO using a simple spreadsheet to make sure that the components are moving within the process according to the FIFO rules. This is particularly important when components are transported in batches. However because of a complication of material matching restrictions and uncertainty in materials recovered from returned items this tool couldn't be fully applied in the disassembly and component remanufacture area. Company C has few products in which it is important to reassemble using the same components that were originally fitted. When the employee is not sure about the quality of any of the parts, he/she leaves that part in a dedicated place. Once a shift, the engineer has checked each of the components a decision is made as to whether it can be remanufactured or has to be rejected from the process. In result, the unit often has to wait for the decision or replacement part, thus FIFO cannot be maintained.

Standardised Work Instructions – All of the Case Companies have implemented Standardised Work Instructions, however, each Manager has highlighted that establishing precise procedures for each operator's work in a remanufacturing process is very difficult and is sometimes not even possible. A manager from Company A, when asked for Work Instructions, said: '*Yes, but not for all operations'* because operations and the time required to remanufacture a particular unit might be different depending on the quality and history of the unit. Company C has highlighted this problem involving the differing quality of incoming components. This is also related to the lack of knowledge of the product's maintenance history. Once, for example, Company C received a core that had components covered by paint which, according to the OEM's specification, had not been done within the original manufacturing process but as result of the maintenance of that product. In that case, engineers had to decide on how to deal with this component to make sure that the required quality standard would be fulfilled. Moreover, the Manager from Company A had mentioned that occasionally when the component was rejected from the process and it was difficult to obtain a new component, the old one had to be remanufactured beyond the economic repair[1] and existing standards. Moreover, the time required to remanufacture units mainly depends on the quality of the incoming core, that is why it is difficult to standardise time for particular activities.

[1] Beyond the economic repair –manufacturing cost of a new component/unit would be lower than the cost of remanufacturing.

Transportation Kanban – Company B and C have implemented Transportation Kanban, however, both managers from both companies admitted that it is not possible to have a Kanban for all components that might be required. The same units might need different spare parts, depending on their quality. Moreover, it was highlighted that an engine which was produced in 1998 might include different parts to an engine produced in 2000. Companies constantly improve their products and implement changes. As a result, having spare parts for all components that will be potentially required for each type of product would require a very big warehouse.

Production Kanban – Company C has said that they have implemented Production Kanban only in the reassembly area. It is difficult to implement Production Kanban in the disassembly and component remanufacture area. In the result of uncertainty in material recovered from returned items, units can be rejected from the process and the customer will not receive the required amount of products. The interviewed manager believes that adding extra parts to each Kanban might solve that issue. However, more research will be required to calculate the amount of these components. Company A and B claim that there are too many uncertainties and problems involved with quality of incoming cores to implement Production Kanban.

Cellular Manufacturing – It is difficult to fully implement Cellular Production within Company B thus depending on the quality, some operations have to be omitted or components need an extra operation. Company A and Company C have implemented the Cellular Manufacturing structure. However, it was also indicated that the problem occurs when an additional operation is required to remanufacture components. Moreover, they have expressed their concern that it would be difficult to dedicate machines and processes to one manufacturing cell because of the high variability of products.

6 Field Work: Validation

Following data collection at the three case study companies, case study reports were sent for review by key informants to ensure all facts gathered were accurate. This review process ensured the reliability of the case study findings.

In addition, findings were also presented to managers and employees from another company unrelated (Company D) for further feedback. Company D was selected for validation as its employees had experience with the application of lean within the remanufacturing environment. Assessing the outcome of the lean transformation journey in Company D wasn't the aim of the validation process. However, to get a better understanding of the level of leanness attained in the organization, the Managers were asked for their subjective judgment. A simplified assessment classification has been developed where 1 represents a low maturity level (manifested in lack of implementation of lean practices), and 6 represents a high maturity level, like in Toyota. Managers rated the maturity of lean within Company D on a 5 out of 6 scale.

During the validation process, interviews with Production and Quality Managers were conducted in an office environment. The visit began with an initial introductory discussion with the managers about the company. After that, the purpose and content of the validation meeting were presented by the researcher. Moreover, the PhD research background aims and objectives were introduced. Then the findings from the Case Study analysis presented in Table 5-8 Lean practices (used by Case Companies) that respond to the particular complexity of production planning and control in remanufacturing identified) and Table 5-9 Lean tools the implementation of which was limited by the complexity of production planning and control in remanufacturing) was displayed on the projector. Each of the identified relationships from each table was explained in greater details by the researcher (to make sure that everyone had the same understanding) and then discussed with the managers. A full explanation was provided (based on the company's experience) to support the answer. Finally, the missing relationships were pointed out by managers and discussed. After the interview, a tour of the facility was conducted. It was valuable to see the processes that were discussed in the office environment.

6.1 An Introduction to Company D

The company has been active in the UK since 1981. The products that are remanufactured within the facility are steering components and transmissions (both manual and automatic), wind turbines. The company is an OEM remanufacturer (most of the products are produced at separate manufacturing sites) and Contracted Remanufacturers (have contracts with certain OEMs but also individual customers like individual wind farms). In the case of car transmissions and car steering, Company D holds contracts with companies like Jaguar, Land Rover. Transmissions for passenger cars, commercial vehicles, and off-road machinery are remanufactured. The remanufactured transmissions go back into the market with the same high quality as in the original equipment and with the same characteristics concerning safety, reliability and driving dynamics. Company D offers remanufactured units for the entire range of steering technology.

Each product is located in a different section:

- Car transmissions section
- Car steering section
- Wind turbine section

First, the product is inspected (incoming inspection) to make sure that it is complete to the specification. Then it is stripped down, cleaned again and various parts are inspected. 100 % of all seals, synthetic and plastic parts are replaced. Some components have to go through machining operations to fulfil quality requirements. Then components are rebuilt and then fully tested.

Lean was introduced in 2004. The main motivation to implement lean was to satisfy customers by bringing products quicker and to ensure that the remanufacturing process is conducted in a timely fashion so the company can meet deadlines. It was noticed that operators have to walk a few kilometres to build a gearbox and as a consequence, the layout was changed.

Managers have admitted that people are the main factor that limits the application of lean within the facility. Employees were stressed about losing their jobs if things would be done faster and easier. That is why communication was an important aspect to successfully implement lean within Company D. An Introduction to lean workshop was organised. Management together with employees took part in training (Lean Lego Game) that was designed to illustrate how Lean practices can make the process more efficient. The Lego session covered many Lean concepts including waste, Kaizen, pull system etc. Apart from the workshop, management constantly assuring employees that lean efforts are not an attempt to reduce jobs. They communicate that if the product will be cheaper, the facility will sell more. Company D will have more work and will need more people to work this successfully. This confirms that the main problem that limits the application of lean within conventional manufacturing and the remanufacturing environment is similar. However, the company have also experienced the challenges/limitations that are only limited to the remanufacturing environment.

6.2 Validation of the Research Findings based on Company D

The findings from this research were presented and discussed within Company D. The company’s application of lean was not a result of this research or as part of this research.

Managers gave feedback based on their experience from the application of lean within their business.

It was confirmed that the Transportation Kanban has relieved the difficulties involved with the uncertainty in materials recovered from returned items. Currently, spare parts are available when required and *'gearboxes flow through the system'* the Manager confirmed. Company D has defined a minimum level of inventory and introduced a Kanban system for the most often used parts. When a number of components drop below the minimum level, it is a signal to order new parts. It ensures that the facility will never run out of critical components. Before Transportation Kanban had been implemented in Facility D, often cores were disassembled at various stages of the remanufacturing process and waiting for spare parts to arrive. It was generating an extra cost and had an influence on customer satisfaction. The manager also emphasised that because of the high variability of products and uncertainty in materials recovered from returned items, not all of the spare parts can be kept in stock. They would need to have a separate building for that reason. The company has completed a study identifying the components pattern usage. This means that the minimum inventory level was defined for the most commonly used spare parts.

Another challenge that was successfully handled within Company D is highly variable processing time. It is a consequence of the application of cross-functional workforce within the facility. Each worker is trained to work on more than one workstation. So when any variability occurs, employees can support the process to deliver the product on time to the customer. A Skills Matrix helps to easily show who can work on what workstation. Inexperienced employees working on difficult workstations might generate mistakes that cause extra work (rework) or customer complaint. Moreover, Company D has introduced a 4-year training program where employees work in each department. The manager has confirmed that the implementation of Standardised Work Instruction has also reduced the highly variable processing time. It helped to eliminate internal variations mainly involved with human resources. Currently, employees work according to work instructions that are displayed on each workstation. A variation involved with machines has been eliminated by Total Productive Maintenance practice. The Company has a system where all machines are registered and the prevention activities are scheduled. This assures that all equipment is available when required (even though the same components taken from different products require different processes to be recovered). Furthermore, it was confirmed that Standard work instructions have an influence on the disassembly of returned products. Establishing precise procedures for disassembly operations helps to reduce variability between different workers/shifts, and make the training of new operators easier. All employees are trained and work according to the best-known way of doing this task. During the meeting, it was also indicated that the standardised work instructions make a positive impact on reducing uncertainty in materials recovered from returned items. This hasn't been discussed in previous Case Companies. Before work instructions were implemented, the decision about rejecting components was made by an employee who performed that task. Currently, the standard defines how the inspection has to be performed and which defects should be discarded (according to available references standard). The manager has said that standardised work instructions (Figure 6-1) brought many benefits to their business despite the fact that not every eventuality could be covered by the standard. It lists the steps of the job, detailing any special knack that may be required to perform the job safely efficiently and to a high standard. The company has defined standards for most operations however in some cases the standard cannot be followed because of the abnormal condition of a particular unit (when for example additional operations are required to fulfil customer requirements). They have also calculated the times required to complete each operation, however, when extra time and effort is required it is performed beyond the standard.

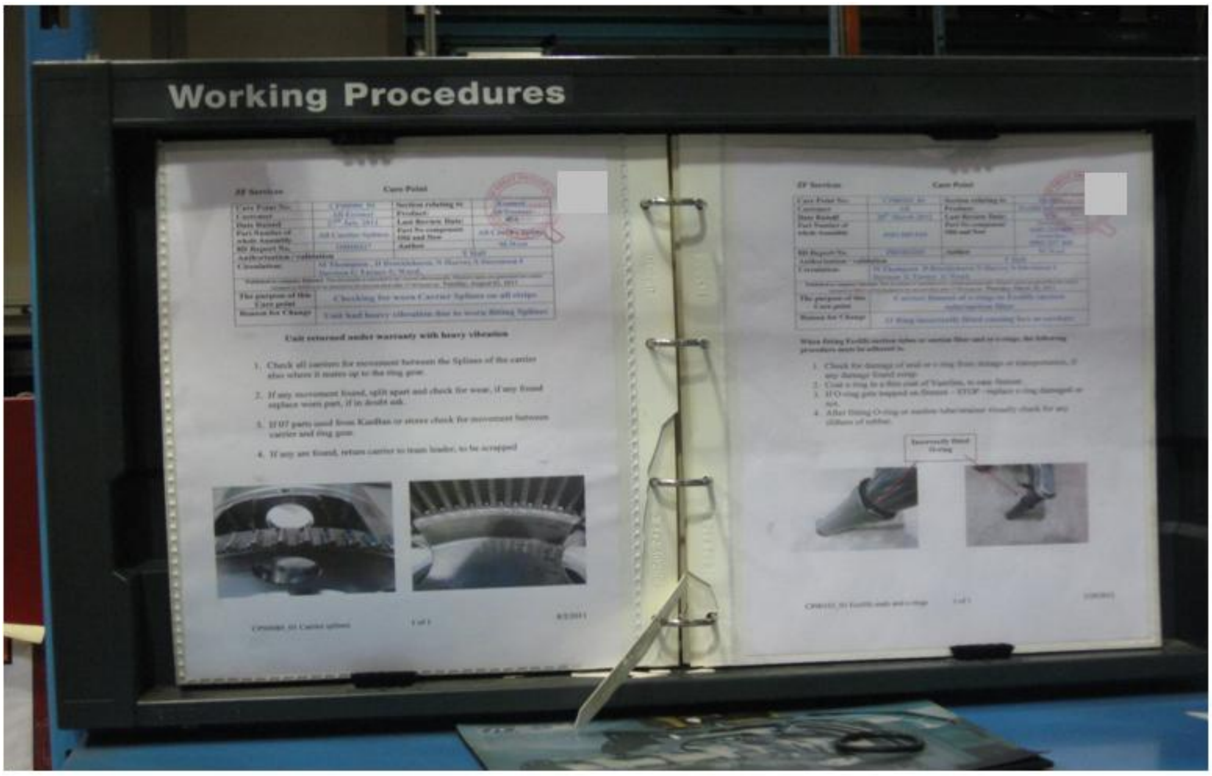

Figure 6-1 Standardised Work Instructions in Company D

When the problem is identified during the remanufacturing operation, the 8D Report (Problem Solving) is used to find the root causes of the problem and to define corrective actions in regards to preventing the problem from ever happening ever again. The new key points are added to the work instructions and employees are trained to a new standard (after the training employees have to sign the list that confirms that everyone is familiar with a new standard). Moreover, it was discussed that solving problems involved with quality of incoming cores allow making the process more stable. Furthermore, everyday managers meet with team leaders to discuss the problems that have occurred during the previous day. Managers have confirmed that if there are unexpected issues involved with quality of incoming cores they are analyzed during such meetings and communicated to other shifts and engineers. As a consequence, corrective and preventive actions are addressed immediately.

The manager confirmed that solving a major failure is important for Company D, however, the system that will allow noticing deviations at every step of the process is also required in regard to releasing the highly variable processing time. The Production Analysis Board hasn't been introduced to Company D but Managers showed an interest in implementing the tool in the future.

Units are transported within the company on custom-build trolleys (standardised transportation boxes, (Figure 6-2), designed for each type of product. Each component is allocated a dedicated spot. It allows keeping all components together through all processes reducing the influence of complication of material matching restrictions on the production planning and control. When anything is missing or discarded it can be easily identified and ordered immediately, thus eliminating the impact of the uncertainty in materials recovered from returned items on the process within Company D. When spare parts are not available on time, the unit has to wait within the process. This results in the customer not receiving the unit on time. In some cases, it takes time to get spare parts, as they are not manufactured any longer. It hasn't been discussed earlier in this research.

Figure 6-2 Standardised transportation boxes within the Company D

The Standardised Kits in terms of work required to remanufacture units were discussed during the meeting. Although the concept hasn't been used, the facility Managers said that they believe that it would eliminate the influence of highly variable processing time on production planning and control within the remanufacturing process. They have highlighted that only very experienced employees would be able to accurately classify incoming cores but if introduced, the resources would be better planned and the customer will always get the product on time.

The impact of highly variable processing time on production planning and control has been also eliminated through the introduction of another lean tool within Company D. Cellular manufacturing has been implemented only within the transmission section where the volume and repeatability are greater than in other areas. Moreover, after disassembly, each component has to go through the same operations despite the quality (opposed to the stochastic routings for material for remanufacturing operations). If the unit requires more work than it was initially planned, the team leader can add an extra employee to the cell to support the remanufacturing process and deliver the product on time to the customer. Skills Matrix helps to make a quick decision on who has the skills and required training to do that work. The manager has confirmed that because of steps in the remanufacturing process often depend on the quality of incoming units (some operations might be omitted or an extra treatment and time will be required - stochastic routings for material for remanufacturing operation), it complicates the application of FIFO. Moreover, because of the complication of material matching restrictions, the whole unit has to be removed from the process and be back when, for example, required component arrives.

Although 5S hasn't been fully implemented within Company D, a lot of benefits have already been recorded. Thus the material and tools are stored at dedicated places that can be seen by everybody at first glance. When an extra operation needs to be performed (as a result of stochastic routings material for remanufacturing operations), time is not wasted for looking for required equipment on a workstation. To sustain the 5S efforts, Company D is planning to introduce regular audits because the lack of self-discipline is the biggest problem.

The same challenges have been released also using another lean concept. The company has implemented elements of the Visual Management (boards with KPI's are displayed in each section. After each shift, the data on board is updated by a team leader). It allows for more easy identification of the status of the operation after just walking onto the shop floor. The manager has confirmed that it supports the identification of any unexpected problems that occur. It was confirmed that the remanufacturing process is significantly exposed to the problems involved with the uncertain quality of incoming units. This causes highly variable processing time. Quick identification of these problems helps in solving them immediately thus delivering the product on time to the customer.

6.3 Summary of the Validation

In this section, a summary of the validation study is presented. The validation exercise confirmed that Company D agreed with most of the findings from case study research, one of the relationships hasn't been confirmed and additional suggestions were made.

The researcher found that Company D was **in agreement** with the findings highlighted below:

- The challenge of disassembling the returned product can be managed by applying the standardised work instructions. It was confirmed that defining procedures for disassembly operations allow reduced variability between different workers/shifts. This is particularly important because disassembly of the used product is difficult and requires knowledge on how to deal with components of unknown quality. Inappropriate handling not only causes longer processing time but can also damage components. Outlined in Table 5-8.
- The complication of material matching restrictions can be reduced by the standardisation of transportation boxes. It was confirmed that when each component is

located in a dedicated place, it allows all components to be kept together throughout the whole process. Moreover, if any component is missing it can be quickly noticed. Outlined in Table 5-8.

- Uncertainty in materials recovered from returned items is reduced by transportation Kanban. Implementation of this practice ensures that the most often used parts are available when required. A minimum level of inventory for such parts has to be defined. When the number of components drops below the minimum level, it gives a signal to order a new one, outlined in Table 5-8.
- Highly variable processing time can be reduced by standardised work instructions, cross-functional workforce, standardisation of kits, production analysis boards, visual management and cellular manufacturing. Managers have confirmed that the remanufacturing process is significantly exposed to the problems involved with the uncertain quality of incoming units that causes highly variable processing times. The implementation of visual management and production analysis boards allow problems to be quickly identified and solved. Standardised work instructions and standardised kits allow for the elimination of internal variations thanks to defined clear procedures for each operator and for the classification of cores. But if the highly variable processing time cannot be fully eliminated, the cross-functional workforce and cellular manufacturing can help in reducing it. Each worker is trained to work on more than one workstation. So when any variability occurs, employees can support the process to deliver the product on time to the customer. Outlined in Table 5-8.
- Stochastic routings for material for remanufacturing operations can be released by 5S and Total Productive Maintenance. Managers highlighted that thanks to the implementation of the 5S practice, time is not wasted for looking for equipment on a

workstation when an extra operation is needed. On the other hand, TPM assures that all equipment is available when required, outlined in Table 5-8.

- Stochastic routings for material for remanufacturing operations limit the application of First in First Out (FIFO), Standardised Work Instructions and Cellular Manufacturing. It was highlighted that some operations might be omitted or extra treatment or time required to remanufacture a particular unit that complicates the application of FIFO and Cellular Manufacturing. It also influences the Standardised Work. In case additional operations are required to fulfil customer requirements, it needs to be performed beyond existing standards. Not all possibilities can be covered by the standards outlined in Table 5-9.
- The complication of material matching restrictions makes the application of FIFO practice difficult. Managers confirmed that in some cases, the FIFO sequence cannot be maintained. For example when the whole unit has to be removed from the process (as a result of the bad quality of one component) and replaced when the required part arrives, outlined in Table 5-9.
- Uncertainty in materials recovered from returned items makes it difficult to apply the application of Standardised Work Instructions and Transportation Kanban. It was highlighted that because of the high variability of products and uncertainty in materials recovered from returned items, not all of the spare parts can be kept in stock (it would require a separate building). The minimum inventory level was defined only for the most commonly used spare parts. Similar to the standardised work instructions. This practice also cannot be fully implemented. Not every eventuality could be covered by the standard and when extra time and effort is required it is performed beyond the standard, outlines in Table 5-9.

- Highly variable processing time limits the application of standardised work instructions. Managers agreed that establishing a time in which an operator performs tasks is difficult. Because similar components taken from different products might require different degrees of treatment for equal operations Table 5-9.

In addition to confirmation of findings from case studies (highlighted above), **additional suggestions** were made by Company D. It was identified that uncertainty in materials recovered from returned items is released by lean practices such as Standardised Work Instructions and Standardisation of transportation boxes (Table 5-8). This relation wasn't identified and discussed in previous Case Companies. The standards define how the inspection has to be performed and which defects should be discarded (according to available references standard). This prevents the subjectivity of employees opinion and helps with the objective process of assessment. Similarly, transportation boxes that contain designed spots for each component, allows it to be easily identifiable when anything is missing and thus eliminate the impact of the uncertainty in material recovered.

The relationship between uncertainty in materials recovered from returned items and Production Kanban (Table 5-9) **hasn't been confirmed**. The interviewed employees in Company D didn't have experience in the application of this practice within the remanufacturing context. Lack of confirmation, in this case, is not equal with disagreement that such relationships exist.

7 Discussion and Conclusions

This research started with the hypothesis that by the adoption of lean strategies, remanufacturers are able to manage effectively, the negative effects of several inherent complexities of the remanufacturing processes, thus making production planning and control (PPC) activities in remanufacturing environments simpler to execute. The study has also discussed the limitations of the application of lean practices in a remanufacturing environment.

7.1 Key Findings

7.1.1 How does the application of lean practices reduce the impact of complexity on production planning and control in remanufacturing processes?

Lean provides several tools for which selection is dictated by the problems that the company is trying to solve. Table 7-1 indicates the development of this research and details the complexities of remanufacturing that might be managed by applying particular lean efforts. The following section discusses which tools have been identified by the case studies as being successfully applied to remanufacturing.

Table 7-1 Opportunities Matrix developed from this research.

		Lean Practices								
		Standardised work instructions	Standardisation(of transportation boxes and kits)	Kanban	Cross-functional workforce	Production Analysis Board	5S	Visual Management	Cellular Manufacturing	Total Production Maintenance (TPM)
Remanufacturing Complexities	Disassembly of returned products	x								
	A complication of material matching restrictions		x							
	Uncertainty in materials recovered from returned items	x	x	x						
	Highly variable processing time	x	x		x	x		x	x	
	Stochastic routings for material for remanufacturing operations						x			x

1. **The challenge of disassembling the returned product**

The challenge of disassembling the returned product can be managed by applying the following methods:

- Standardised Work Instructions

All interviewed managers confirmed that disassembly of the used product is difficult as it requires knowledge on how to deal (e.g. grip, clean, remove etc) with components of unknown quality. Typically this knowledge is developed by a company over time. Working with worn or eroded components is always problematic but 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 of existing automated techniques that can be used during disassembly, this, in turn, makes this task very labour-intensive with highly variable processing times. Usually, each employee has his/her technique on how to perform this operation. More experienced employees have the knowledge of how to disassemble parts without damaging them thus reducing scrap etc. They know for example that on some parts they should use penetrating (i.e. low viscosity) lubricant to make disassembly easier (i.e. requiring less force). A less experienced employee may not know this and consequently will try disassembling not using any oil. Many of the parts can be broken by the excessive torques applied and the disassembly process will take much more time as a result. To reduce this variability, best practices for disassembly should be documented and then shared with all employees to make such operations more effective. Employees are encouraged to share best practices. In other words, experienced employees should not keep tips on how to perform particular tasks to themselves, but make such information explicit so other employees can learn. Standardised work processes, once established should be displayed at the workstation, and continuously reviewed and improved.

2. The complication of material matching restrictions

The complication of material matching restriction can be eased through:

- Standardisation (Standardisation of transportation boxes)-

In some remanufacturing operations, cores have to be reassembled using the same components (e.g. for safety reasons or customer requirements). The company has ensured that this requirement is fulfilled. Having several cores at the same time, within a process, make this difficult. A process adopted as part of the “kitting process” by Company B is the standardisation of boxes with specifically-designed spaces for each component of the product. Boxes designed in such a way to ensure that all required components for a specific product can be kept together and allows any omissions to be instantly recognised. This helps to keep all components with the same serial number together and ensures reassembly with the correct combination of components.

3. Uncertainty in materials recovered from returned items

Uncertainty in materials recovered from returned items can be alleviated by applying the following methods:

- Transportation Kanban

In most remanufacturing processes, (depending on the quality of core) some components will be replaced with new ones. It is difficult to predict how many new components will be required. In conventional manufacturing, it is much easier to calculate (when the company is planning to produce, say 1000 units, the number of components is known and these have to be ordered). In remanufacturing, company planning specialists have to keep track of new components consumed in the remanufacturing process and predict how many components should be ordered to fulfil the future remanufacturing plan. To support component supplies transportation Kanban can be implemented. Transportation Kanban gives permission to material handlers to move components. The safety stock level for each part has to be defined based on the time required to buy a new one. The safe level can be represented in a number of parts or other measures, for example, a level on a scale. When the stock is below that line or number, it is a signal that new components have to be ordered. The employee taking the first part which is below the required number or line is responsible for placing the Kanban card on the board. This is a signal for the planning, or purchasing specialist to order more components. This system assures that stock is constantly available but is not excessive. It makes planners' life easier as they don't have to keep track of how many components were used every day. Previously planners had to try to predict how many components will be required. With Kanban, the order is made based on the need of the remanufacturing process. However, unfortunately, because of the high variability of products, not all required components can be kept in stock and when more unusual items are required they are ordered when they are needed for production.

- Standardised Work Instructions

The interviewed employees in Company D indicated that Standardised Work Instructions reduces the negative effect of uncertainty in materials recovered from returned items. Before the application of that tool the decision whether the component can be used or rejected from the process, was mainly based on employees' experience. Thus this task could be performed only by experienced employees because the consequence of the wrong decision had an influence on the whole business. Wrongly rejected components cost money. Keeping components that had to be rejected in the next operation caused also additional cost and unnecessary confusion. After the implementation of Standardised Work Instructions, there are clear guidelines according to which the components are assessed.

- Standardisation (Standardisation of transportation boxes)

Transportation boxes with dedicated spots for each component are used in Company D. Remanufacturers have to purchase the replacement for parts that cannot be reused from cores in advance so the process will not have to wait for the parts. When they are not available on time, the unit has to wait within the process. As a result, the customer will not receive the unit on time. Interviewed employees suggested that having all components placed in this type of transportation box allows for quick identification when any component is missing or had been discarded in any step of the process. It is important to purchase the replacement part on time. In the past, often, information about the missing parts wasn't available until the reassembly. As a result, the company had to keep a higher stock of spare components to react to such a situation.

4. **Highly variable processing times**

Highly variable processing times can be relieved through the application of:

- Cross-functional workforce.

Highly variable processing time is a challenge that most remanufacturing companies have to deal with and one consequence of this is that some operations might require much more time and human effort than anticipated. When an operation requires more time than was initially planned for, a decision can be made to assign an additional operator to the job. But this will only be possible if there is an operator who is also qualified to work on that workstation without supervision. Consequently, it is critical to have multi-skilled employees to help reduce the uncertainties associated with the quality of incoming cores. Employees that can work in more than one process area, increase flexibility and simplify the remanufacturing planning process. A skills matrix (a visual representation of all employees and the qualifications that they have in regards to each workstation operation), enable managers to visually recognise which employee has required competencies to support particular operations.

- Standardisation(Standardisation of Kits)

It is difficult to plan a remanufacturing process because of the uncertainties in the quality of incoming cores. Introducing the standardization of kits appears to offer advantages for remanufacturers. Defining standards in terms of the work required to remanufacture as light, medium or heavy, helps to reduce levels of uncertainty involved with the different conditions of products/components. Before the process starts, an engineer inspects the components and classifies them as a medium-light or heavy kit. Each type of kit has defined time and effort that is required to remanufacture core. This is important information for planning specialists so they can more precisely plan the remanufacturing process. The case studies demonstrate the advantages of using such an approach.

- The Production Analysis Board

The hourly production boards allow the identification of problems at the lowest level of management. Introduction of this tool helps to illustrate the process and make any problems immediately visible. The boards are placed nearby the production workstation and they show what the plan is and how the remanufacturing process is performing from hour to hour. When the workstation does not accomplish the plan, the leader needs to write down the cause. Because in remanufacturing new problems involving the quality of incoming cores show up constantly it is very important to be able to identify them so the process can be improved. Every few hours, or at least once during a shift, the production manager together with the engineer analyzes the identified problems. Even if the problem cannot be 'solved' within the facility, the knowledge is still important information for the planning specialist who can note that the time required to remanufacture this type of defects is longer.

- Standardised work instructions

Variability in employee skill, as well as the core, can also cause processing time to vary. So to reduce such internal variation, standardised work instructions have been implemented by all 3 case companies. Best practices (i.e. the currently best-known way of performing a task) for each operation was identified, documented and then shared with all employees to make operations more efficient. Managers confirmed that this is a powerful tool that allows the visualization of the overall activities of the process.

- Cellular Manufacturing.

In conventional manufacturing, depending on production volume, a number of employees can work within a cell to fulfil customer demand. Similarly in a remanufacturing environment, depending on the quality of incoming product and time required to complete work a number of people can work within the cell. The managers in Company A and Company C confirmed that elements of this practice have been used within their facility because no matter what the quality of the unit is, each one has to go through all the operations.

- Visual Management

The visual control boards display performance status and communicate problems. Any deviation that occurred within the process is discussed each day. Very often these problems result in similar parts requiring different degrees of treatment for each remanufacturing activity. It was confirmed that the identification of such abnormalities is critical in regards to improving the process. Solving identified problems ensures that the processing time is more stable. Even though the problem cannot be solved straight away, the process can be better planned to consider identified issues and their requirements. For example, when the performance indicators are below the expected level, the shift leader can make a decision to move an extra employee to support the more demanding operation to fulfil the customer requirements on time.

5. Stochastic routing of the material

Stochastic routing of the material can be accommodated through the application of:

- 5S

The 5S method can be implemented as a form of visual management. So, if the order is not being maintained at the workstation, (e.g. the material is not stored in their correct locations, tools are not put back to the appointed place). 5S allows everybody to see it at a glance. It also helps to keep discipline at the station, so when an extra operation needs to be performed on a workstation, time is not wasted by looking for tools that are required. This is particularly important in remanufacturing where so many uncertainties exist.

- Total Productive Maintenance (TPM).

The deployment of TPM can help to ensure that remanufacturing equipment is available whenever a particular operation is required. It is a way of increasing the reliability of production machinery.

None of the lean practices studied was effective at reducing the challenges involved with:

- Uncertain timing and quantity of returns,
- Need to balance returns with demands,
- The requirement for a reverse logistics network

However, this could be due to the scope of the research which was limited to Production planning and control. Further work to broaden the scope of the investigation to cover Logistic and Supply Chain Management might identify other opportunities for lean methods within the remanufacturing environment.

7.1.2 How does the complexity of the remanufacturing process limit the application of lean practices?

This research has concentrated on the major complexities of the remanufacturing process (described in chapter: Remanufacturing Challenges) and how these challenges limit the application of lean tools and practices within a remanufacturing environment.

Table 7-2 indicates the development of this research and presents which of remanufacturing complexities influence the application of lean tools within the remanufacturing environment.

Table 7-2 Threats Matrix developed from this research.

		Lean Practices				
		First In First Out (FIFO)	Standardised Work Instructions	Transportation Kanban	Production Kanban	Cellular Manufacturing
Remanufacturing Complexities	Stochastic routings for material for remanufacturing operations	x	x			x
	Uncertainty in materials recovered from returned items		x	x	x	
	Highly variable processing time		x			
	The complication of material matching restrictions	x				

1. **Stochastic routings for material for remanufacturing operations**

Stochastic routings of material for remanufacturing operations limit the application of particular lean tools:

- First In First Out (FIFO)

It was confirmed that it is difficult to ensure that the first part that enters a process, or a storage location is also the first part to exit in remanufacturing environments because similar parts might require different processes (e.g. some operations might be omitted or components will have to go through additional treatments to fulfil customer requirements). Furthermore, in some cases, components have to go through the same operation again. As a result, parts/units often leave the system in a different sequence from which they entered (Figure 7-1).

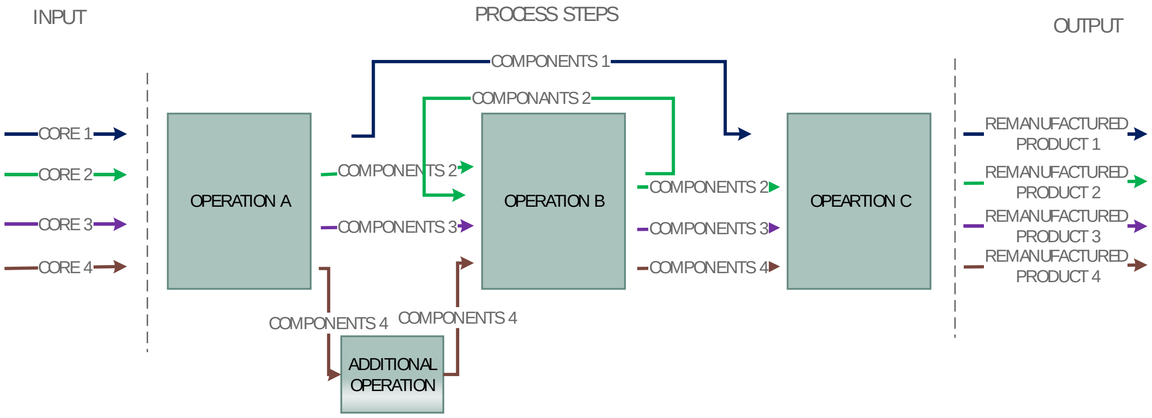

Figure 7-1 FIFO in the remanufacturing environment

- Standardised work instructions

It was already confirmed that standardised work instructions have been implemented within a remanufacturing process, however, establishing precise procedures for each operator's work is difficult. The Introduction of standards assures that every operator performs each task in the defined sequence which helps to create repeatability in the process (Obara and Wilburn, 2012). It was previously mentioned that remanufacturing contains additional characteristics that increase inconsistency within the process. Depending on the quality of returns, similar parts may need different processes to be recovered. Moreover, very often additional activities (that are not covered by existing standards) are necessary to bring a product to the required condition. In that case employees' cannot perform the activity repeatedly and their experience is invaluable.

- Cellular Production

It is difficult to fully implement Cellular Production when not every remanufacturing operation is required. In some companies, regardless of the quality of the core, the components have to pass all operations. However, in other remanufacturers, the quality is assessed and based on that components are sent to the operations that are required. This was the case in Company B, where depending on the quality, some operations could be omitted or component will need extra operations (Figure 7-2). Moreover, the interviewed Manager admitted that it would be difficult to dedicate machines and processes to one remanufacturing cell.

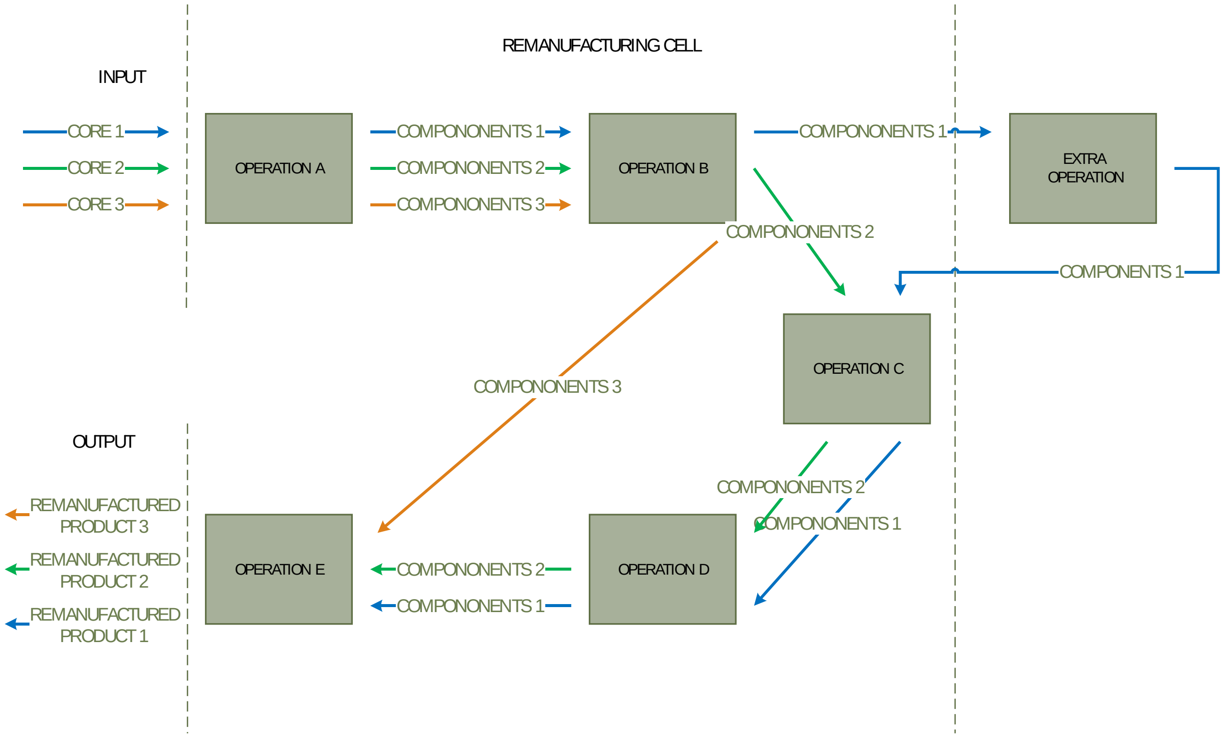

Figure 7-2 Cellular Manufacturing in the remanufacturing context

2. Uncertainty in materials recovered from returned items

This study has confirmed that uncertainty in materials recovered from returned items limits the following lean practices:

- Transportation Kanban

It was confirmed that the implementation of Transportation Kanban can be possible only for particular components. As a consequence of the high variability of products and uncertainty in materials recovered from returned items (depending on the quality, different sets of spare parts might be required to remanufacture similar units), it would not be feasible to keep all parts that might be required to remanufacture each unit. Moreover, there is also a risk of component obsolescence.

- Standardised work instructions

This research has already confirmed that that standardised work instructions can be implemented within the remanufacturing process, however, establishing precise procedures for each operator's work in a remanufacturing process is difficult. Not all possibilities can be covered by standards. For example, uncertainty in materials recovered from the returned items is difficult to predict and so what parts will be required to remanufacture a particular unit. Very often, because of the age of the cores, a significant amount of time is required to obtain spare parts. When the customer doesn't want to wait, non-standard operations are required to provide missing components. Very often the old component is remanufactured beyond economic repair[2]. Each case/component has to be separately discussed with engineers in regards to fulfil the quality standard.

- Production Kanban

As a result of the uncertainty in material recovered from returned items, components can be rejected from the process and the company has to put much more effort to fulfil the customer order on time (Figure 7-3). Adding extra parts to each Kanban might solve that issue however, more research is required to calculate the quantity of these components. Kanikuła and Koch, (2010) have identified nine scenarios of material and information flows developed within their Lean Remanufacturing methodology. In all of those scenarios, a Kanban system was successfully presented. However, scenarios were developed under certain conditions. One of them was the *rate of using new parts is known*. The remanufacturers have to acquire the replacement for parts that cannot be reused from cores. The lack of knowledge of how many components will be rejected from the process is the main complexity of the remanufacturing process.

[2] Beyond economic repair – the effort required to repair is higher that the cost of newly produced component.

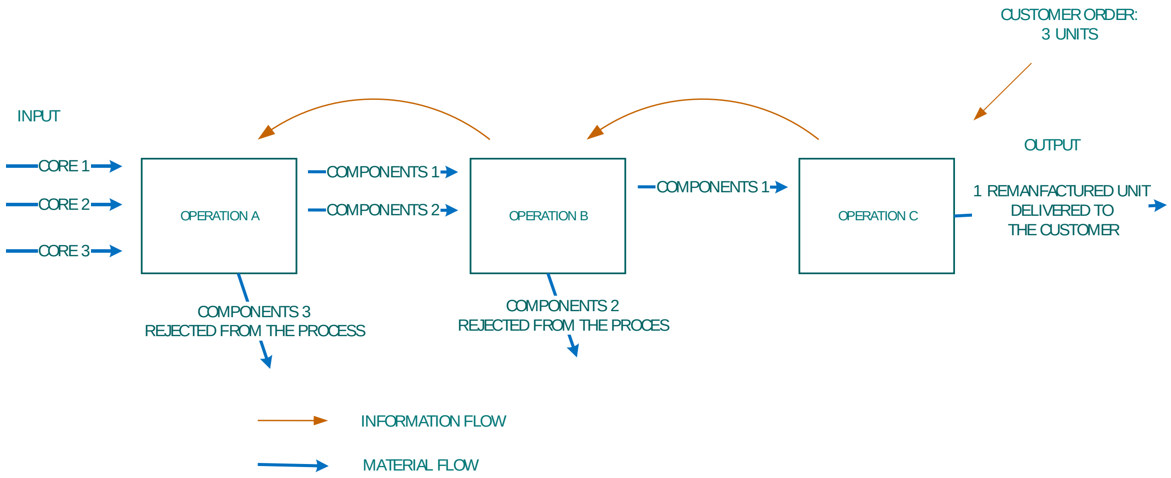

Figure 7-3 Kanban in the remanufacturing context.

3. The Complications of material matching restrictions

Both the complications of material matching restriction and uncertainty in materials recovered from returned items make difficult to apply FIFO within the remanufacturing process

- First In First Out (FIFO)

Often cores have to be reassembled using the same components that were originally fitted. When the quality of any such component is not good enough, it has to be taken out of the process and a decision has to be made if it has to be rejected from the process. When the component cannot be remanufactured, a new one has to be obtained. This results in the whole product being removed from the process and re-introduced when the new component arrives.

4. Highly variable processing time

This study has identified the highly variable processing time limit in the application of the following lean practices.

- Standardised work instructions

Standard times required to perform each activity should be established and included in the work instructions (Obara and Wilburn, 2012). To do that, various techniques and technology might be used (such as a video camera, computers etc.). Damiani (2016) presented a concept of evaluating a video recording that observes the same operations repeated five times. The longest and the shortest time have to be removed and three remaining times are averaged to establish the cycle time of that activity. Similar components taken from different products might require different degrees of treatment for equal operations.

However, it was also observed that the frequently stochastic nature of process sequences during remanufacturing operations, uncertainty in materials recovered from returned items highly variable processing time and complications of material matching restrictions can limit the implementation of the lean practices within that remanufacturing context. All of these challenges arise from the uncertainty about the quality of incoming units.

7.1.3 Similarities between Opportunities Matrix and Threats Matrix

Chapter 7.1.1 and chapter 7.1.2, presents the research objectives that have been achieved by providing explicit, rigorous and unambiguous answers to each of the research questions. Two Matrices has been developed to visualise findings from this study. It has been noticed that three relationships between lean practices and complexities of the remanufacturing process occur in Opportunities Matrix and Threat Matrix.

It was identified that the uncertainty in materials recovered from returned items can be released by standardised work instructions and, at the same time, limits the implementation of this practice. The decision-making process is mainly based on employees' experiences that influence the uncertainties in materials recovered from returned items. It was confirmed that the standardised work instructions, gives clear guidelines on which of the components are assessed. This prevents the assessment of the components from being dependant on employees' experience. Also, because of uncertainty in materials recovered from the returned items, it is difficult to predict what parts will be required to remanufacture a particular unit. Very often, because of the age of the cores, a significant amount of time is required to obtain spare parts. When the customer doesn't want to wait, non-standard operations are required to provide missing components. Not all possibilities can be covered by standards. In this case, each component has to be separately discussed with engineers to fulfil the quality standard.

Highly variable processing times can be relieved through the application of standardised work instructions and at the same time highly variable processing time limits the implementation of this practice. Establishing precise procedures for each operator's work can reduce the variability caused by the employee's skills. However standard times, required to perform each activity, that are part of the standardised work instructions, are difficult to establish and include in instructions within the remanufacturing environment. Similar components taken from different products might require different degrees of treatment for equal operations.

Uncertainty in materials recovered from returned items can be alleviated by applying the Transportation Kanban. At the same time, the study has confirmed that uncertainty in materials recovered from returned items limits the implementation of Transportation Kanban. As already mentioned, it is difficult to predict what parts will be required to remanufacture a particular unit and thus difficult to predict how many components should be ordered to fulfil the future remanufacturing plan. To support component supplies, transportation Kanban can be implemented. Transportation Kanban gives permission to material handlers to move components. The safety stock level for each part has to be defined based on the time required to buy a new one. However, as a consequence of the high variability of products and uncertainty in materials recovered from returned not all required components can be kept in stock. When more unusual items are required they are ordered when they are needed for production.

7.2 Contribution to Knowledge

7.2.1 Theoretical Contribution

The research developed in this study expands a more holistic understanding of the application of lean within the remanufacturing environment. There are several outputs of this study, which result in contributions to knowledge:

- Opportunities Matrix – new knowledge on how the applications of lean practices reduce the impact of complexity on production planning and control in remanufacturing processes. It demonstrates the impact of particular lean practices on specific complexities of the remanufacturing process.
- Threats Matrix - new knowledge about the application limits of particular lean tools within the remanufacturing process (Threats Matrix) has enlarged the body of knowledge in lean remanufacturing. It points out which lean practices are affected by which complexities of the remanufacturing process. Lean is not a process of implementation (of best practices), but a process of discovering what we need to learn in order to improve. As such, the best practices become frames to accelerate learning (Ballé, 2019). Thus, further research should focus on these limitations, particularly how these lean manufacturing best practices may evolve to be better suited to addressing the challenges of remanufacturing firms.

The validation study confirms the usefulness and relevance of Matrices also for practical application. Thus, the matrices not only provide an original contribution to knowledge but also to the practical field.

7.2.2 Practical Implications

The research is also significant from an industrial perspective. Practitioners can use this study to choose a suitable lean practice to overcome the negative effect of remanufacturing complexities, thus making PPC activities in remanufacturing simpler to execute. An

Opportunities Matrix has been designed to be a rough guide for remanufacturing managers to chose the right lean practice. For example, when a complication of material matching restrictions make production planning and control difficult to execute, managers can make a decision that the standardisation of transportation boxes should be implemented within the facility.

7.3 Limitations of the Study and Future Work

There were a few limitations noticed in the course of undertaking this research. Some of these were anticipated during the research design phase; others emerged during the research execution. Three types of limitations have been recognised: those related to the scope of the study, those related to the research methods deployed and few emerged as a result of the execution of the research. These limitations are a source for potential future research and these are as follows

Scope of the research – Given that this research has been part of one person's PhD, the research study is inherently limited to the amount of time that can be spent on it. Considering the time restrictions, the scope of this research is mainly focused on the remanufacturing process. As a result of the complexities of the remanufacturing business such as uncertain timing and quantity of returns, need to balance returns with demands, and the requirement for a reverse logistics network hasn't been discussed. Further investigation should cover the Logistic and Supply Chain Management Departments, which may further develop Opportunities and Threats Matrices. The degree of generalization needs to be treated with caution, as only firms in the automotive sector were sampled. It can be argued that enterprises in other sectors, even though facing similar constraints, may respond differently in applying lean principles. This calls for future research into some form of comparative analysis. Further research should focus on other industries. In order to broaden the research, it may be appropriate to undertake similar studies across other business sectors such as the toner cartridge or mobile phone remanufacturers etc.

Research Methods – Given the nature of the phenomenon under study, influenced by the researcher's world views, this research has taken the form of a qualitative study. The case study methodology was chosen as an effective method for capturing qualitative data. Moreover, it was decided to restrict the study to three case companies on the basis that three is enough to build a rich picture and large enough to permit generalizability. However, a richer understanding would have been gained using just one case. In order to explore further findings of the Threats Matrix, it is recommended to chose action research and follow the implementation of lean practices such as FIFO, standardised work instructions, Kanban or cellular manufacturing to adapt such practices to the remanufacturing context.

Emerged as a result of the execution of the research – Given the small, yet growing size of the remanufacturing industry, the researcher was restricted to a limited pool of companies who were available and suitable to take part in the research. It was difficult to gain commitment from industrialists to give up their time to support a piece of academic work. From six companies that were initially selected and then visited for main research, only three were finally used during the data analysis stage. To get a better understanding of the potential case companies and the level of leanness attained in this organization a website search was done and contact with companies representative's by email and phone took place before the visit. However, a full assessment of the lean transformation journey in case companies was only possible during the visit. Since there are plenty of remanufacturing companies that haven't implemented lean practices within the remanufacturing environment, there is an opportunity for further research. The researcher didn't take part in the implementation of the discussed lean practices. In conclusion, there is a lack of quantification of the effects of applying lean within the remanufacturing environment. Further research should develop a set of KPI’s that should be measured and recorded before and after implementation of each lean practice.

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9 Appendix

I. Appendix I - Interview Questionnaire – Pilot Case Study

A. General Information

1. What kinds of products are remanufactured within the facility?
2. When was lean first introduced to the facility?
3. What was the motivation to introduce lean within the facility?
4. Can you describe the implementation (very briefly)? What makes this journey particularly interesting?
5. Did you have any experiences with the implementation of lean within the manufacturing environment?

B. Process

1. What does the process look like? Does it differ in regards to the product type?
2. What problems are involved with production planning and control within the remanufacturing process you are facing?
3. What problems did you face in the past and have you managed to overcome these using lean practices?

C. Lean Practices

1. What lean practices have you implemented?
   a) What are the benefits of this implementation?
   b) What difficulties (if any) have you faced during this implementation?
2. What lean practices couldn’t be implemented? Why?
3. Which of the discussed tools was the most beneficial for the remanufacturing process? Why?
4. What in your opinion is the main/key difficulty involved with the implementation of lean practices within your facility?

II. Appendix II - Interview Questionnaire

A. General Information

1. What kinds of products are remanufactured within the facility?
2. When lean was first introduced to the facility?
3. What was the motivation to introduce lean within the facility?
4. What does this implementation look like (very briefly)? What makes this journey particularly interesting?
5. Did you have any experiences with the implementation of lean within the manufacturing environment?
6. (adequate for OEM) Did you have any support with the implementation of lean from the experienced manufacturing part of the company?

B. Process

1. What did the process look like? Does it differ in regards to the product type?
2. What problems are involved with production planning and control within the remanufacturing process you are facing?
3. Does 'uncertain timing of returns' influence and complicate PPC activities within your business?
   a) Did you face that challenge in the past? If yes, how did you overcome it?
4. Does 'uncertain quality of returns' influence and complicate PPC activities within your business?
   a) Did you face that challenge in the past? If yes, how did you overcome it?
5. Does 'need to balance returns with demand' influence and complicate PPC activities within your business?
   a) Did you face that challenge in the past? If yes, how did you overcome it?
6. Does 'disassembly of returned products' influence and complicate PPC activities within your business?
   a) Did you face that challenge in the past? If yes, how did you overcome it?
7. Does 'uncertainty in materials recovered from returned items' influence and complicate PPC activities within your business?

a) Did you face that challenge in the past? If yes, how did you overcome it?

8. Does ‘requirements for a reverse logistics network’ influence and complicate PPC activities within your business?

a) Did you face that challenge in the past? If yes, how did you overcome it?

9. Does ‘complication of material matching restrictions’ influence and complicate PPC activities within your business?

a) Did you face that challenge in the past? If yes, how did you overcome it?

10. Does ‘highly variable processing times’ influence and complicate PPC activities within your business?

a) Did you face that challenge in the past? If yes, how did you overcome it?

11. Does ‘stochastic routings for materials for remanufacturing operations’ influence and complicate PPC activities within your business?

a) Did you face that challenge in the past? If yes, how did you overcome it?

C. Lean Practices

1. Which of the following wastes exist in your process?

a) Waste of overproduction

b) Waste of waiting

c) Waste of unnecessary transportation

d) Waste of over-processing

e) Waste of unnecessary inventory

f) Waste of unnecessary motion

g) Waste of defects

h) Waste of non-utilised talent

2. VSM/VSD - Was a material and information flow diagrams developed for depicting the remanufacturing process? What consist of VSM? Did you develop Value Stream Design?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

3. Did you face any challenges determining takt time and c/t? Because the quality of cores can differ, does it affect the takt time and c/t?

   a) What are the benefits of this implementation?

   b) What difficulties (if any) have you faced during this implementation?

4. Andon - Is production stopped when defected components are detected?

   a) What are the benefits of this implementation?

   b) What difficulties (if any) have you faced during this implementation?

5. Poka-Yoke - Are mistake-proof and fail-safe concepts practised through the organisation?

   a) What are the benefits of this implementation?

   b) What difficulties (if any) have you faced during this implementation?

6. 5S

   a) Sorting - Are all unnecessary tools, parts eliminated from the workplace? Having in mind the variability in products and their quality was it possible to introduce Sorting?

   b) Simplify - Does everything in the workplace have a defined place and everything is in this place?

   c) Systematic Cleaning – Is the workplace tidied and cleaned regularly? Is it more difficult to keep the workstation tidy, when the used products are usually covered by oil sand etc?

   d) Standardise – Were standards developed for the first 3S?

   e) Sustain – Are area or workstations audits carried out?

   f) What are the benefits of this implementation?

   g) What difficulties (if any) have you faced during this?

7. Total Productive Maintenance (TPM) – Do you ensure that every machine in production always can perform its required task?

   a) What are the benefits of this implementation?

   b) What difficulties (if any) have you faced during this implementation?

8. Overall Equipment Effectiveness – Do you measure how effectively equipment is being used?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

9. Single Minute Exchange of Die (SMED) – Does a process for changing over production equipment from one part number to another is as little as possible?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

10. Standardisation – Did you establish precise procedures for each work and process?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

11. Visual Management – Does a visual labelling system identify and locate inventory, tools and processes? Are updated charts on productivity, quality, and safety visible?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

12. FIFO - Do you ensure that the first part that enters the process or storage location is also the first part to exit?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

13. Kaizen - Do you organise a group kaizen activity, in which teams identify and implement improvement in a process?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

14. Do you use a Kanban signal that gives authorization and instructions for the production or withdrawal of items?

a) What are the benefits of this implementation?

b) What difficulties (if any) have you faced during this implementation?

15. Cell – Is the location of processing steps for a product immediately adjacent to each other so that parts can be processed in a very nearly continuous flow, either one at a time or in small batch size?

    a) What are the benefits of this implementation?

    b) What difficulties (if any) have you faced during this implementation?

16. What other lean practices have been implemented within your facility, besides those already discussed?

    a) What are the benefits of this implementation?

    b) What difficulties (if any) have you faced during this implementation?