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A strategic operations framework for disassembly in remanufacturing

by

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ABSTRACT

Previous studies into the field of disassembly have widely focused on both product attributes. These attributes include the number of components, product structure, type of materials and other geometrical information. From a management perspective, disassembly that focuses on these attributes is categorised as operational issues, which deal with day-to-day decisions. On the other hand, organisational characteristics and process choices, which are strategic in nature, have generally been overlooked by previous investigations.

Some studies have attempted to include such variables in their analysis, but these studies were not comprehensive. This research therefore endeavours to address this oversight by investigating disassembly from an integrative perspective that incorporates organisational characteristics, process choices and product attributes. This inductive study features five remanufacturing companies as case studies in order to develop a comprehensive framework of disassembly strategies. The selection of the companies was not random, but rather took into consideration their potential for providing theoretical insights.

The study starts by outlining a new process model of disassembly for remanufacturing, followed by a comprehensive identification of factors affecting disassembly. It incorporates organisational characteristics, process choices and product attributes. The five companies are then grouped into four quadrants, according to these factors, and the strategies within each group are analysed in order to develop the framework of the disassembly strategies, which is the main contribution of this study.

The key findings of this research are: (1) remanufacturers in Quadrant I, which disassemble cores with low complexity and high stability supply, *rely on disassembly resources flexibility*; (2) remanufacturers located in Quadrant II, which disassemble cores with low product complexity and high stability supply, *attempt to exploit the benefits of high volume of production*; and (3) remanufacturers in Quadrant III, which disassemble complex cores in high stability supply, *endeavour to maximise recovered value* from the cores. No company was classified as belonging in Quadrant IV, which disassemble cores with high complexity but lack of stability. The

generalisability of the framework has been confirmed by a panel of experts. The members of the expert panel are academia and practitioners that have an extensive knowledge in this field. This study could be criticised on the basis of its small sample size; however, the validity and reliability criteria are fulfilled to ensure that the results represent its objectivity.

1. INTRODUCTION

The topic of this PhD is: *A strategic operation framework for disassembly in remanufacturing companies*. This topic falls under the major theme of sustainable manufacturing, which has received considerable attention in recent years. This is partly because of a growing trend within government bodies, such as European Union Directives, Waste Electrical and Electronic Equipment (WEEE), Kyoto Protocol and End-of-Life Vehicles (ELV) in favour of adopting more environmentally friendly manufacturing practices and regulations. Economic analysis has shown remanufacturing to be a prospective business (Subramoniam et al. 2009) and it is environmentally friendly from an ecological perspective (Hatcher et al. 2011). This is because remanufacturing is not only viewed as an effective way to minimise discarded waste, but also as part of a company's manufacturing and marketing strategy (Saavedra et al. 2013).

Geographically, concerns surrounding environmentally friendly manufacturing practices are no longer dominated by the US and European countries. China, for example, has been actively engaged in implementing sustainable manufacturing, particularly remanufacturing. To support this implementation, the country has set up a strategic plan to develop the remanufacturing industry (Zhang et al. 2011). Japan (Matsumoto & Umeda 2011; Ramstetter 2011), India (Rathore et al. 2011; Mukherjee & Mondal 2009; Abraham 2011) and Australia (Kerr & Ryan 2001) have all adopted similar practices.

In terms of product types, automotive products are the most common (Saavedra et al. 2013), but other product types, such as photocopiers (Walsh 2009; Mukherjee & Mondal 2009; King et al. 2006), forklift trucks (Östlin et al. 2008), toner cartridge (Östlin et al. 2008) and telecommunication devices (Franke et al. 2006; Rathore et al. 2011) are all gaining in popularity. This evidence indicates that remanufacturing has spread widely across many countries and product types.

This significant increase in attention towards remanufacturing practices suggests that more studies in this area are badly needed. Such a study would contribute to a better understanding of remanufacturing, which would in turn lead to more economically feasible and environmentally friendly manufacturing practices. This research aims to fill this particular need by investigating how remanufacturing companies could improve their remanufacturing processes through a better-managed disassembly process.

In particular, this study aims to contribute towards a better understanding of remanufacturing practices through the organisation of more appropriate disassembly strategies. Remanufacturing performance can be improved by minimising uncertainties (Aksoy & Gupta 2010), with disassembly being one of the main causes. Moreover, the uncertainties from disassembly may affect other processes in remanufacturing such as cleaning, testing and reassembly. Thus, better-managed disassembly, better-managed disassembly will lead to more economically efficient remanufacturing operations. A discussion about the effects of disassembly on other processes will be presented in Chapter 5, Section 5.3.1.

1.1. Significances of disassembly in product recovery

Disassembly is a critical element of product recovery activities, as it is the key link that connects product return with product recovery (Du et al. 2012), and a prerequisite for some processes. Disassembly is a prerequisite for reprocessing and re-machining because the processes cannot be carried out whilst the components are still embedded in the products. In other processes, for example cleaning and testing, the components do not have to be entirely disassembled from the products; however, partial disassembly may still be necessary.

In this case, products must be disassembled to a certain level in order to give access to certain components so that cleaning and testing can be carried out. Without disassembly it may not be possible for other processes in remanufacturing to be undertaken, which would mean the products could not be remanufactured.

Disassembly is also the main gateway of information, where many data that is related to the remanufacturing operations originates (Junior & Filho 2012; Guide Jr. 2000). Information is valuable in order to minimise any uncertainties in activities that are related to remanufacture, such as purchasing new parts, inventory management and production planning and scheduling (Ferrer & Ketzenberg 2004; Ferrer 2003; Ferrer

& Whybark 2001). The importance of information from disassembly increases when remanufacturers deal with complex products (Ferrer & Ketzenberg 2004).

Disassembly is the main feature that distinguishes product recovery activities from conventional manufacturing operations. Existing studies have devoted less attention to disassembly that is specific to remanufacturing because it is generally assumed that the process is identical to the disassembly process performed in other recovery methods. This is incorrect as several distinctive features make it more complicated (Thierry et al. 1995). Within remanufacturing, the components that result from the disassembly process need to be brought to a condition that is as good as new, so that they can then be reassembled into as-new products.

Resources from manufacturing, which are mostly assembly processes, cannot be fully adopted in disassembly. Some methods used in manufacturing, such as component testing, assembly and inspection, can be adopted in part by remanufacturers during some of the processes, but they should not be adopted in disassembly. As the disassembly process does not exist in conventional manufacturing, it is very difficult – if not impossible – to use conventional manufacturing methods, techniques, tools and equipment for disassembly. Moreover, specialised tools and equipment may be required in order to minimise any defects because products are mostly designed for assembly, rather than disassembly (Sundin & Bras 2005; Guide Jr. 2000).

Uncertainties that arise on the disassembly shop floor can affect other processes in remanufacturing. During disassembly, not all of the parts can be recovered. It is rare to achieve full recovery rates, so there is an increase in the need for new parts (Guide Jr. 2000). As disassembly is cited as the main source of parts during reassembly (Ferrer & Whybark 2001) and availability of parts is the most costly operation in remanufacturing (Hammond et al. 1998).

Based on the significance of successful disassembly demonstrated above, the overall remanufacturing process can be enhanced by improving disassembly. Hammond et al. (1998) state in their survey report that disassembly is one of the most serious problems that is found in remanufacturing and, therefore, improving disassembly could improve overall remanufacturing processes. The ability to manage disassembly is the key to success for remanufacturers because it affects several other parameters, including lead times, price, delivery and quality (Duflou et al. 2006).

The remanufacturing process differs according to the products, with each showing a different return flow, characteristics, yield and potential value of recovered components (Ferrer 2003). These differences imply that these factors require different disassembly strategies. To support his opinion, Ferrer (2003) provided some examples within his conclusion. Xerox, in Venray, Holland, disassembles all of the components once the cores have arrived at the facility; while its counterpart in Lille, France, only remanufactures the components that are needed urgently. The design of these strategies is based on prior experience regarding the yield obtained during disassembly of the cores. Thus, to support remanufacturing, the disassembly strategy should be aligned with the remanufacturing strategy.

1.2. Type of research required

There has been an abundance of research conducted regarding disassembly that concentrates on product disassembly as the focus of the investigation (Ilgin & Gupta 2010). Many of the studies that investigate disassembly do not mention the ultimate purpose of product recovery from disassembly. The final purpose of disassembly is important because disassembly for remanufacturing is different from that of other recovery methods. The output of remanufacturing should be able to offer quality performance at the same level, or higher, than the new condition, whereas other recovery methods do not offer such a performance specification (Ijomah et al. 2004; Thierry et al. 1995).

To support end-of-life strategies, the organisation should react to the way the products are designed. Successful end-of-life strategies cannot rely on product design rather it should consider organisation and supply chain to support product recovery (Gehin et al. 2008). For this reason, themes related to organisational characteristics, such as the type of remanufacturers (Lund 1984; Lind et al. 2014), relationships with core suppliers (Östlin et al. 2008; Lind et al. 2014) and knowledge transfer regarding products knowledge (Inderfurth 2005; Gehin et al. 2008; Saavedra et al. 2013) should also be covered. Similarly, issues in process choices such as the use of automation (Franke et al. 2006; Sundin et al. 2012) and employee skills (Ferrer & Whybark 2000; Behdad et al. 2012) need to be incorporated. These are just a few examples of issues that should be incorporated into a comprehensive study of disassembly in remanufacturing.

From a methodological point of view, the majority of these studies utilised positivist paradigms by using operations research with assumptions that are difficult to fulfil in real life situations (Flynn et al. 1990). Accordingly, conducting research by using different methodology and philosophical stances, combined with comprehensive factors affecting disassembly, would provide a significant contribution to existing knowledge.

1.3. Research objectives

The main objective of this research is to extend existing research of disassembly for the purpose of remanufacturing by integrating the influential factors that were discussed in the previous section. Here, the aim of the research is to examine disassembly for remanufacturing from a strategic operations management perspective. This research does not aim to offer a static formula to be applied as-is, but rather to provide generic guidance that could be useful to managers of remanufacturing companies drafting their strategy for disassembly.

Two research questions are proposed that have arisen from a critical analysis of the literature. An exploratory literature review in Chapter 2 will provide further details of how these research questions arose from the review. The research questions are:

1. *RQ1: What are the factors that affect disassembly for remanufacturing?*
2. *RQ2: How do remanufacturing companies manage disassembly based on the factors affecting it?*

The objectives of this research, guided by the research questions above, are as follows:

- To identify what has been understood about disassembly and the drawbacks from current studies. *An exploratory literature review has been carried out to accomplish this aim and is shown in Chapter 2.*
- To develop a new process model of disassembly, describing how the new model affects other remanufacturing processes and identifying how disassembly for remanufacturing differs from that of other recovery methods. *A systematic literature review has been carried out in Chapter 5 to understand how disassembly in remanufacturing works. From here, a new process model of disassembly in remanufacturing is developed, its differences with that of other recovery methods as well as the factors that affect disassembly will be identified.*
- To examine the factors affecting disassembly in remanufacturing. *A systematic literature review to identify the factors affecting disassembly has been conducted in Chapter 5, and then empirically analysed based on the findings from case studies discussed in Chapter 7. It is important to stress here that the term 'disassembly' will be based on the new process model that is proposed in Chapter 5. The results of this stage will provide the answer for Research Question 1.*
- To analyse disassembly strategies that have been adopted by remanufacturing companies. *Multiple case study methodology and company visits were conducted as shown in Chapter 8. In the company visits there were observations, interviews, document checks and discussions. The results of this analysis provide the answer for Research Question 2.*

1.4. Thesis structure

Figure 1.1 depicts the structure of this thesis, showing the researcher's questions on the left-hand side, the contents of the chapter on the middle, and the outcomes and contributions on the right-hand side. The contributions of this research are shown in blue, in both the text and the boxes.

Issues	Chapters	Outcomes
• Why is this topic important? • What are the research questions and objectives of this study? • What is the structure of the thesis?	**Chapter 1: Introduction** Overview of the topic, its significance and research questions	Understanding of: • The importance of the topic • The research questions and objectives of this study • Description of the thesis structure
• What is the current state of research in this topic? • What are drawbacks of existing research • What are the research gaps?	**Chapter 2: Literature review: identification of research gap** RQ1: What are the factors that affect disassembly for remanufacturing? RQ2: How do remanufacturing companies manage disassembly based on the factors affecting it?	• The map of existing research in the topic • The drawbacks of existing research are justified • The research gap is identified and justified
What are the possible research methodologies for conducting this research?	**Chapter 3: Research methodology** Discussion of a wide range of philosophical approaches and methodologies to carry out research	Various possible options for conducting the study are identified
• How should I conduct this research? • Why do I chose certain choices to carry out research instead of others?	**Chapter 4: Research design** How this research would be undertaken and why certain design is selected	• An appropriate research method for conducting the study is justified • Techniques and methods for carrying out analysis are explained
• How disassembly in remanufacturing works? • How disassembly in remanufacturing is different from that in other recovery methods? • What factors affect disassembly in remanufacturing found in existing studies?	**Chapter 5: Understanding disassembly in remanufacturing context** – A systematic literature review. To gain understanding on disassembly for remanufacturing	***Contribution to knowledge*** • A new process model of disassembly for remanufacturing • Differences between disassembly for remanufacturing and that for other recovery methods are identified Factors that affect disassembly in remanufacturing are identified from existing literature.
What are the answers for RQ1 and RQ2 within each individual case?	**Chapter 6: Within case analysis** Analysis of the answers for RQ1 and RQ2 within individual case as an independent entity	A description of the answers for RQ1 and RQ2 within the individual case as an independent entity
What are the factors that affect disassembly as demonstrated in the case studies?	**Chapter 7: Factors affecting disassembly: empirical findings** Factors identified from a systematic literature review are analysed against	***Contribution to knowledge*** The 17 factors that affect the disassembly process for remanufacturing are identified
• How do remanufacturing companies manage disassembly process? • Is the strategy to manage disassembly valid and useful to academics and practitioners?	**Chapter 8: Development of disassembly strategy framework** Emerging patterns from within case analysis in Chapter 5 are compared	***Contribution to knowledge*** A disassembly strategy framework for remanufacturing companies is developed.
	Chapter 9: Conclusion Summary of the research and its findings	• Assessment on the quality of research • Contribution to knowledge • Limitations and areas for further research

Figure 1.1. Structure of this research

This thesis is composed of nine chapters, each with different objectives. Each chapter begins with a brief description of its objectives and how it relates to previous chapters. At the end of each chapter is a summary that is concerned with to what extent the objectives have been achieved, and how the results of the corresponding chapter connects to the next chapter. The nine chapters of the thesis are summarised in Table 1.1.

Table 1.1. Thesis structure

Chapter	Description of contents
1. Introduction	This chapter starts with the introduction of some key concepts of the topics, then describes the importance of the topic in this thesis, and finally outlines the approach and structure. This is necessary to give the reader a broad understanding of the area in which this research is being carried out.
2. Literature review: Identification of research gap	This chapter aims to map what has been carried out by other researchers and identify the drawbacks of the studies and any research gaps that can be identified. The outcome of this chapter is a map of the literature review and a research gap identified, providing the starting point of this study.
3. Research methodology	This chapter discusses a number of possible research philosophies and methodologies that can applied in this research. The case study method, which will be applied in the subsequent chapter, will be discussed in detail.
4. Research design	This chapter presents a more detailed discussion of how the selected methods and techniques are applied. These include the justification of certain decisions, including the selection of philosophical stance, case study design, unit of analysis and data collection methods.
5. Understanding disassembly in remanufacturing context – A systematic literature review.	This chapter uses a systematic literature review to achieve three aims. First, to understand how disassembly for remanufacturing works; second, to identify differences of disassembly for remanufacturing with that for other recovery methods, and last, to identify factors that affect disassembly for remanufacturing. The factors that are identified from existing research will be used as constructs to answer Research Question 1.
6. Case studies	This chapter attempts to analyse the answer to both Research Questions 1 and 2 within each case as a separate entity. The analysis in this chapter is based on empirical evidences in individual case study.
7. Factors affecting disassembly – Empirical findings	This chapter analyses the answer for Research Question 1 by using cross-case analysis. The findings from different cases are analysed and emerging patterns across the cases are analysed to find the answers for Research Question 1. Due to the deductive nature of Research Question 1, the findings from the case studies are analysed against the constructs prepared in Chapter 5.
8. Development of disassembly strategy framework	This chapter aims to answer Research Question 2. Factors affecting disassembly that have been identified in Chapter 7 will be used as a point of departure. The factors affecting disassembly will be classified as the basis to determine how the case companies organise their disassembly process.
9. Conclusion	The final chapter provides a brief review of the research aims, then summarises the key findings from previous chapters, and finally outlines the implications to practice. Limitations of the research and some directions for further research are also presented.

2. LITERATURE REVIEW – Identification of a research gap

This chapter attempts to achieve two aims. First, provides a theoretical foundation upon which the research has been built. Second, discusses existing research into the topic of disassembly to identify a research gap. Current studies, which are analysed throughout this exploratory literature review, will be used to identify the studies that have already been conducted into the topic and to examine the gaps that exist in current studies (Croom 2009; Wacker 1998). In addition, this literature review will examine whether the identified research gap is an extension of existing works, or is entirely a new research (Tranfield et al. 2003).

2.1. Current research into disassembly

There are several features that make disassembly different from assembly. The major difference is that the former is a divergent process, whereas the latter is convergent. To be more specific, the differences are (1) the end result of disassembly cannot be predicted precisely, (2) the input of disassembly varies greatly, (3) disassembly involves the unfastening of joints that might be combined with some destructive tasks (e.g. cutting and breaking), rather than the fastening actions of assembly, and (4) the position of the parts are not identified clearly (Das & Naik 2002).

According to a survey undertaken by Das and Naik (2002), there are three factors that determine if disassembly is successful. First, the ability to carry out disassembly when there is limited data available regarding product specification. Second, the ability to implement disassembly with limited time and effort; and third, the classification of fasteners in the products and tools that are used to disassemble the products. There is no doubt that, in order to overcome these issues, companies need to employ talented staffs to undertake disassembly (Ferrer & Whybark 2000).

An abundant number of studies have been conducted into disassembly in general and parts of them have been devoted to remanufacturing. However, it seems that there has been no study that has attempted to integrate all of the factors with comprehensive analysis. As can be seen in Figure 2.1, the studies into disassembly for remanufacturing are segregated into many specific topics.

2.1.1. Decisions in disassembly

When focusing on the attributes of a product, there are three main decisions that need to be made about disassembly. These are: the level of disassembly, the sequence of disassembly and the method of disassembly. These decisions have to be made in any disassembly process, regardless of the recovery methods. Since these decisions are related to the attributes of products, such as the geometry of the products, the number of components and the product structures, it is not surprising that a large amount of research is being carried out which focuses on product design (Desai & Mital 2005; Zwolinski & Brissaud 2008). The three decisions in disassembly create uncertainties which affect other activities in remanufacturing such as purchase of new parts, preparation of Material Requirement Planning (MRP) and reassembly (Ferrer & Whybark 2001; Klausner et al. 1998). The next sub-section will discuss this in more detail.

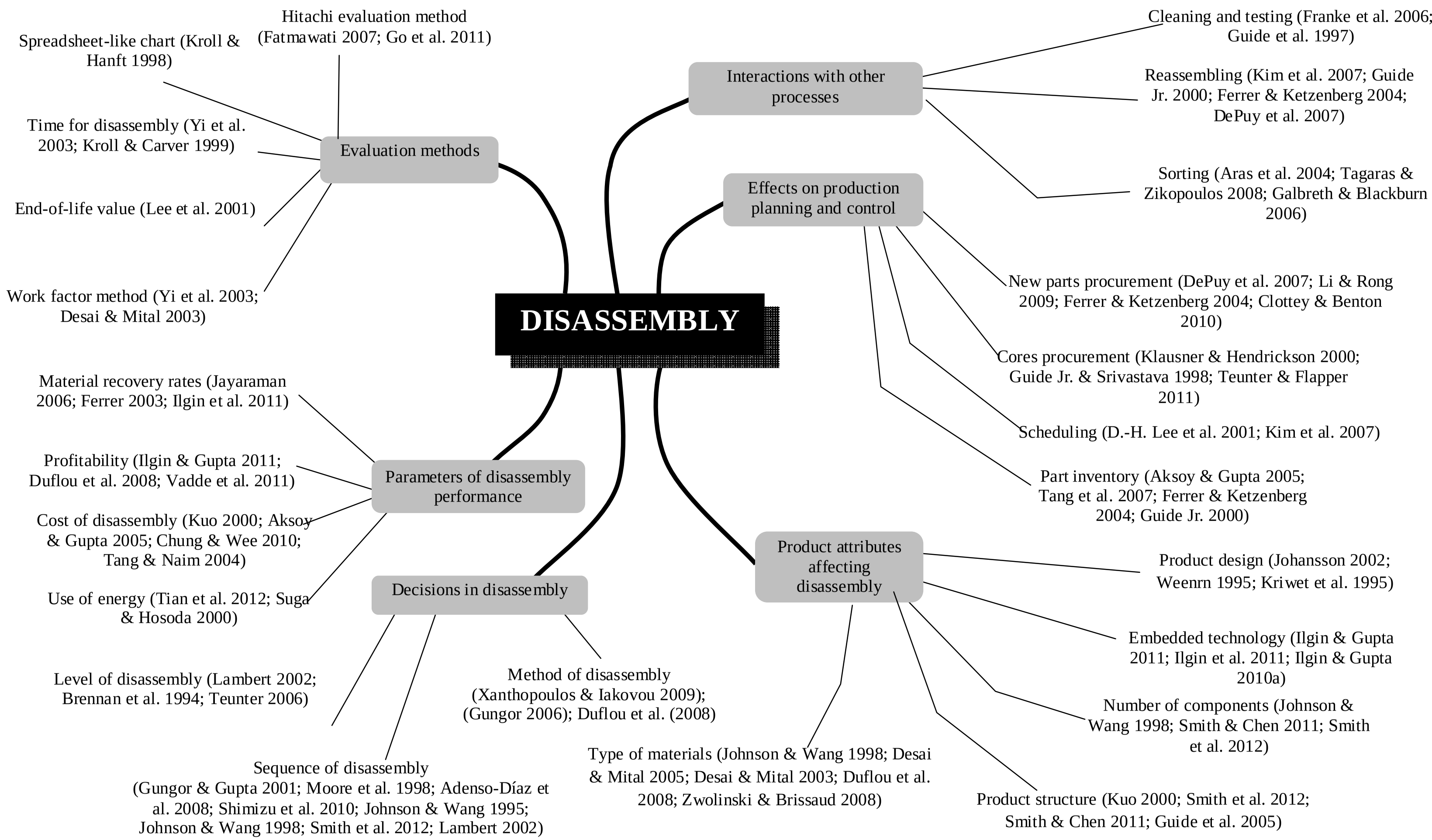


Figure 2.1. A map of existing research in disassembly

2.1.1.1. Methods of disassembly

Companies have to make a judgement as to whether the potential residual value of the components make disassembly profitable (Gungor 2006). If it is too expensive to disassemble an item non-destructively, then destructive disassembly would be the last option. In certain cases, particularly when there are high concentrations of homogenous materials or products of high value due to their distinctive materials (e.g. printed circuit boards), direct shredding would be the preferred option (Das & Naik 2002).

Xanthopoulos and Iakovou (2009) investigate whether companies should carry out a destructive or non-destructive process for different type of recovery methods. Their research considers attributes of the products and other factors, such as time, the level of demand and the reverse logistics network selected by companies. Duflou et al. (2008) examine non-destructive disassembly in computer monitor and they reveal that product design is important as this affects how much time it takes to disassemble. Furthermore, they found that destructive disassembly is easier to automate than the non-destructive.

2.1.1.2. Level of disassembly

The level of disassembly can be categorised as either complete or incomplete. Complete disassembly, which is sometimes called full disassembly, refers to when a product is dismantled into the lowest level, and every constituent part is separated.

On the other hand, the term incomplete disassembly was introduced by Lambert (2002) and can be categorised further as either partial or selective disassembly. Selective disassembly refers to a process of dismantling the desired components from a product, without causing any damage to the parts and products. The desired components have been identified from the outset, before disassembly takes place (Brennan et al. 1994).

With partial disassembly, the product is dismantled step-by-step, without any prior specification, until it reaches the level where it will stop. In short, the planning that takes place in partial disassembly is less clear than it is in selective disassembly. Partial disassembly that focuses on disassembling certain components is, in many cases, more profitable than full disassembly (Teunter 2006).

2.1.1.3. Sequence of disassembly

Disassembly sequence refers to how the best order of activities to separate components from a product (Ilgin & Gupta 2010). Scholars have investigated the disassembly sequence for a number of reasons. First, certain sequences of disassembly can minimise the costs (Moore et al. 1998) and reduce the risk of component damage (Adenso-Díaz et al. 2008). Second, the disassembly sequence is useful in the development of an intelligent control system that can be used as the foundation of automated disassembly. Third, the solution obtained from the analysis of disassembly sequence could also be utilised to give feedback to designers to help them design the products. This implies that the optimum disassembly sequence and product design both interplay with one another (Shimizu et al. 2010).

The condition of the cores might affect the disassembly sequence. Due to the age of the products, the condition might have deteriorated to the extent that they are easy to break during the disassembly process. To avoid this, the sequence should be altered to avoid any broken parts (Gungor & Gupta 1998).

2.1.2. Evaluations methods

Evaluation methods for disassembly can be broadly categorised into two categories: absolute and relative metrics (Kroll & Carver 1999; Go et al. 2011). The metrics included in absolute measures are time, cost, energy and entropy for disassembly, while examples of relative metrics are design effectiveness and the difficulties faced in disassembling. In comparison to absolute metrics, data for relative metrics is more difficult to obtain and define, which consequently justifying the objectivity of the analysis is more difficult (Go et al. 2011). Absolute metrics are also better than relative metrics in comparing different product design alternatives. This is because the former does not provide information about how good the design is or how to make improvements to it (Kroll & Carver 1999). In addition to these differences, there have been many publications that investigate the quantitative methods, but less works examine the qualitative methods.

2.1.2.1. Hitachi Design Evaluation Method

The Hitachi Design Evaluation Method (DEM) is a quantitative method that measures ease of disassembly. The method, developed by Hitachi Limited, evaluates whether, and to what extent, the product design improves the time it takes to disassemble the product. The method uses a 100-point scale score, along with time estimation (Fatmawati 2007).

Since this method focuses on the importance of product design, it is suitable for new products. It works well only if the details of the products are known, such as the number of parts, the shape of the components, the product structure and the disassembly sequence (Go et al. 2011). Improvements could be made by examining the disassembly time in the existing design and by proposing a new design which improves that time.

2.1.2.2. Spread sheet-like chart

This method, which is used to measure ease of disassembly, was developed by Kroll and Hanft (1998). Five parameters are used to assess the ease of the disassembly of products. These are: accessibility, positioning, force, additional time and special. Each product is assigned a score that indicates its ease of disassembly, which ranges from 1-10. The result of the score shows the design effectiveness of the product, which indicates to what degree the design of the products support disassembly. The Spreadsheet-like chart is primarily applied to new products to improve their disassemblability, in a similar way to the Hitachi Disassemblability Evaluation Method. The main limitation of this method is that it considers geometrical products without making an economic evaluation assessment (Go et al. 2011).

2.1.2.3. Time for total disassembly

Time is a critical factor in the disassembly process. By understanding what factors affect the time required to carry out disassembly, remanufacturers can improve the disassembly time. Kroll and Carver (1999) have developed a time-based parameter to measure disassemblability. Time is chosen as the parameter because the length of time that is needed to disassemble can be used to assess the disassemblability of products. There are various factors that affect disassembly, and understanding them can be an effective way to measure the disassemblability of products. These factors include: the age of products, the type of materials, whether they are painted/coated, the degree of wear, and the ease of tightening. To simplify the products disassemblability for recycling, Kroll and Carver (1999) developed factors that are attributed to product disassemblability, including accessibility, positioning, force and base time.

Other scholars who use time as a parameter for disassembly, like Kroll and Carver (1999), are Yi et al. (2003) According to Yin et al., the following factors affect disassembly time: (1) the time it takes to identify the joint elements, (2) the time it takes to search for and identify tools, (3) the time required for gripping tools, (4) the time it takes to moving between the joint elements, (5) the time required for redirecting towards the side of the joint elements, (6) the time it takes to align between the tool and joint element, (7) the time needed for tool operation area, (8) the time for basic separation of joint element, (9) the time for intensity of work, (10) the time it takes for post-processing due to weight, (11) the time needed for post-processing due to the movement of disassembled parts, and (12) the time it takes for post-processing due to hazards.

2.1.2.4. End-of-life value

Gupta & Isaacs (1997) developed a tool that can be used by designers to assess the potential value derived from disassembly and recycling. They used goal programming to minimise trade-offs between technological, economic feasibility and the degree of environmental effects. Lee et al. (2005) developed a method for determining the optimal level of disassembly of end-of-life products. In order to maximise the benefits derived from disassembly, one should minimise the environmental effects, which are associated with cost and maximising the return.

2.1.2.5. Work factor method

Scholars refer to two works that are associated with this method. The work of Yi et al. (2003) is a comprehensive study that combines both the factors of work and time. The logic behind their model is that work factors determine how much time is spent on disassembly. The work factors presented in their model consist of 4 elements, which are moving body parts, the distance of movement, weight of resistance and artificial control. They also develop a list of activities that require time during the disassembly process and are affected by work factors.

The second method is proposed by Desai & Mital (2005). This more recent methodology consists of two components: the numeric disassemblability evaluation score and the systematic application of design for disassembly methodology. The numeric disassemblability evaluation score can be broken down into several design parameters, including the degree of the accessibility of components, the amount of force that is required to disengage components, the positioning of the tools for disassembly purposes, and the requirements of tool and design factors, such as the weight, shape and size of components. Meanwhile, the numeric disassembly score consists of two elements. These are: the assignment of end-of-life options to each component and the evaluation of numeric indices that affect disassemblability.

2.1.3. Parameters of performance

2.1.3.1. Material recovery rates (MRR)

MRR can be calculated in a number of ways but all of them represent the expected yield of from cores. The value of MRR can range between 0 – 1.00, where 1.0 indicates all materials can be recovered (Jayaraman 2006). MRR of some products are more predictable but others are more difficult to estimate due to lack of available data. MRR can be used as guidance when companies develop MRP and determine the lot size of new parts purchasing plan. Most remanufacturers utilise historical data to develop a purchasing plan (Guide Jr. 2000).

The uncertainties of MRR affect some processes in remanufacturing. Companies that have low recovery rates tend to have a higher number of stocks, a high holding cost and a large amount of capital tied up in raw materials. Cores that have low recovery rates require a larger number of new parts in warehouse as remanufacturers are only able to recover a small portion of components from the cores (Subramoniam et al. 2009). In addition to this, due to a lack of information pertaining to MRR, it is difficult to identify new part requirements and, therefore, new parts orders should be released at a very short planning horizon from the planned due date (Guide Jr. 2000). Moreover, the number of resulting parts, the quality of disassembly, varying recovery rates and the uncertain demand for components could change the production planning process for remanufacturing (Sutherland et al. 2002).

2.1.3.2. Profitability

Disassembly that is organised by OEMs results in a better recovery value and greater profitability. This is due to the fact that OEMs possess a better knowledge about the products, so that unnecessary work can be avoided (Duflou et al. 2008). Ilgin & Gupta (2011) considered various costs (such as holding, backorder, disassembly, disposal, testing and transportation cost), total revenue and profits in their investigation. In their analysis, they revealed that the use of embedded technology can significantly reduce the amount of holding, back orders, disassembly, disposal, testing and transportation costs, and therefore increase the amount of revenue and profits. Vadde et al. (2011) use a multi-criteria decision model to assess the disassembly performance. In their model, a combination of the amount of profit and inventory level is used as a measure of performance. The central idea of the model is how to stabilise inventory fluctuations so that the cost is minimised while profit is maximised.

2.1.3.3. Cost

The disassembly cost should be evenly distributed across the resulting components regardless of their value. Accordingly, disassembling low value components will only increase the average cost that is assigned for each of the components, so as to reduce the potential the yields of high value components (Tang et al. 2004).

Many studies have investigated disassembly with cost minimisation as the objective. One of the comprehensive studies that analysed the cost of disassembly was carried out by Kuo (2000). He found out the disassembly cost is a function of both labour cost and disassembly time, assuming that disassembly is carried out manually by operators. Aksoy and Gupta (2005) attempted to minimise the disassembly cost by optimising throughput time. While Aksoy and Gupta focused on their investigation into remanufacturing in general, Chung and Wee (2010) focused on the cost of disassembly. Their research attempted to optimise both replenishment and production-inventory-distribution, so that the optimum cost of disassembly could be achieved.

2.1.3.4. Use of energy

A number of studies have examined energy as a disassembly performance parameter. Tian et al. (2012) are among the scholars who attempted to combine energy and recovered value from cores. Disassembly is considered as optimum when the amount of energy that is spent has been minimised and the recovered value is maximised. Suga and Hosoda (2000) proposed a number of conditions of products with high disassemblability. These were: lower disassembly energy, lower energy entropy, a smaller number of interconnections and parts, shorter disassembly paths, smaller and lighter parts, through the communication of the disassembly information and active disassembly.

2.1.3.5. The links between the parameters of performance

There are the links between the parameters of performance. There is some causal relationship between the parameters. For example, higher MRR can lead to reduced cost (Johnson & Wang 1995) and improved profitability (Jayaraman 2006). Similarly, the use of a parameter can provide indication on how the performance of other parameters. An example on this case is work factor method and cost. Work factor methods can be indicators on how much cost that the companies have to spend (Desai & Mital 2005). In this case, the higher the amount of work that the company spent, the higher the cost that remanufacturers have to spend.

Despite there is some link between the parameters, they are not perfect substitution one another. Rather, they are complementary with different emphasis. For example, cost and MRR are strongly related as the decision to disassemble depends on how much cost that the company has to spend. The higher MRR the higher the likelihood that disassembly is feasible economically. This is because MRR determines the residual value of cores while the cost of disassembly should be at least equal to or higher than the value of components coming from recovered materials. Cost was intended for economic analysis while MRR was intended for technical analysis particularly during reassembly phase. Thus, low cost, which indicate economic feasibility, does not necessarily lead to feasible from technical perspective.

There is some relationship between parameters that are typically used from different perspectives. A good example of this is energy, profitability and cost. The use of energy is typically used to measure performance from environmental perspective while profitability and cost are from economic perspective. Despite they are used to measure performance from different perspective; they are related in some ways. Products that are disassembled using a smaller amount of energy will need lower cost and thus produce higher profitability. Thus, products that are more environmentally friendly are also more interesting from economic perspective (Tian et al. 2012).

2.1.4. Interactions with other processes in remanufacturing

2.1.4.1. Cleaning and testing

Guide et al. (1997) examined scheduling policies for remanufacturing and disassembly was one of the processes included in their analysis. They demonstrated that the disassembly release mechanism is useful in preventing a large number of parts from queuing in the entry operations in the other processes after disassembly has taken place, including cleaning and testing. Thus, the disassembly release mechanism is useful in managing the queuing time. Franke et al. (2006) investigated how manual and automated disassembly is related to cleaning and reassembly during remanufacturing process. Integration of automated disassembly with other processes, such as cleaning, is needed in products with innovative products, for example mobile phones, to meet the challenge of short product life cycles.

2.1.4.2. Reassembling

Part matching during the reassembly process is affected by the success of part recovery during disassembly (Kim et al. 2007). The main problem is that there is low visibility regarding the need for part replacements. A very short planning horizon adds to this complexity (Guide Jr. 2000). In many cases, remanufacturers rely on the vendors of new components in case there are missing parts because they cannot be recovered from cores (Ferrer & Ketzenberg 2004). Companies experience extreme difficulties in matching parts if they totally rely on components from the cores because it is very rare that a core can be recovered 100 per cent. It is also possible to cannibalise two or more cores and build them into a final product but there is still no guarantee that part matching can be achieved 100 per cent. Given the uncertain nature of component recovery and the recovery rates, the number of finished products is also uncertain (DePuy et al. 2007).

2.1.4.3. Cores sorting

Although sorting is not always present in all remanufacturing companies, it provides benefits, not only to the disassembly process, but also to the overall processes in product recovery (Aras et al. 2004). Cores sorting helps remanufacturers to manage material flows and increase their economic viability during disassembly. Tagaras and Zikopoulos (2008) demonstrated how eliminating the sorting process could lead to a significantly higher disassembly cost. When remanufacturers spend some more of their financial resources in organising sorting, the cost of disassembly drops significantly.

As more cores are available for remanufacturing, the sorting criteria are tighter and cores with a lower remanufacturing cost only that can proceed to the next process. The cost of obtaining a large number of cores to some extent reduces the remanufacturing cost through the increased quality of cores that enter the remanufacturing facility (Galbreth & Blackburn 2006).

2.1.5. Production planning and control

2.1.5.1. New parts procurement

The outcome of disassembly is not only affected by the relationship between parts and subassemblies, but also by the subsequent remanufacturing processes and demand for the new parts (Li & Rong 2009). Decisions regarding the *when* (DePuy et al. 2007), *how many* and *which* new components (Ferrer & Ketzenberg 2004) to order depend on output from the disassembly shop floor. In addition, since the orders are usually released in small quantities, it is not easy to find a vendor who is willing to fulfil the demand for new parts in small qualities within a short time constraint. As a consequence, the lead time for new part orders is extremely variable (Ferrer & Ketzenberg 2004). Other factors that should be considered are the order lead time, inventory holding costs and the stock out cost of new parts (Tang et al. 2007).

Sophisticated forecasting techniques that use computer modelling are not popular amongst the remanufacturers to deal with new part procurements. Remanufacturers rely on managerial judgements that are typically carried out on a short term basis. Despite the forecast is conducted on short-term basis, it seems that the managers lack of confidence as indicated by the modifications that are made frequently (Clottey & Benton 2010).

2.1.5.2. Cores procurement

The continuity of cores supply is an important consideration for a remanufacturing business (Klausner & Hendrickson 2000). Due to the uncertain nature of cores supply, many remanufacturing companies develop inventories. These inventories are not only for using cores as the raw materials for remanufacturing, but also for the work-in-process between different processes in remanufacturing (Guide Jr. & Srivastava 1998). It is extremely difficult, if not impossible, for remanufacturers to develop zero inventory of raw materials due to the uncertain arrival time of cores.

High volume of cores can be used as production levelling in almost remanufacturing process, including disassembly. Accordingly, continuity of cores supplies can help disassembly shop floor to reduce idle capacity and increase utilisation rates (Vinodh et al. 2012). A lack of attention on the quality of cores can result in either not enough cores or too many. An increase as low as 1% in uncertainty over the cores' quality can lead to an increase in costs by 5% (Teunter & Flapper 2011).

2.1.5.3. Parts inventory

Remanufacturers can develop stocks of new parts in anticipation of the needed parts in reassembly process. The use of the parts inventory increases the average operating cost and also the due date performance at the same time. With an increase in due date performance, the ability of companies to fulfil their customers' needs will increase and, consequently, customer satisfaction and profitability will increase as well (Aksoy & Gupta 2005). To do this, remanufacturers have to determine the optimum inventory level because they need to create a balance between the holding cost of new part stocks and the potential of the stock out cost (Tang et al. 2007; Ferrer & Ketzenberg 2004). To reduce inventory cost of new parts, remanufacturers should attempts to increase amount of parts recovered from cores. With the increase in recovery rates, the dependency on the new parts can be reduced and purchasing cost for the new parts can be minimised (Jayaraman 2006).

2.1.5.4. Scheduling

The output of disassembly sequence planning can be used as the input for disassembly scheduling because the former is more detailed than the latter. Disassembly sequence planning consists of detailed activities, such as components, sub-modules and modules that need to be disassembled, as well as how products will be disassembled, and how much time is needed to carry out disassembly. When all of the detailed activities are combined, they can be an input for preparing the disassembly schedule (Lee et al. 2001).

Disassembly scheduling does not merely deal with the decision when to disassemble, it also extends to other decisions, including planning for inventories and managing resources for setting up a facility. Regarding the inventory, disassembly scheduling is concerned with how to manage inventories of disassembled components. Inventories in the disassembly process are more complex than assembly, since the former is a divergent process in which the amount of output is much larger than the input. Facility set-up is also important, especially in manual disassembly that can take a long time to complete, as it can create a bottleneck for the overall disassembly process (Kim et al. 2007).

2.1.6. Product attributes

There have been many studies using quantitative methods published in engineering and operations research journals such as Computers & Industry, European Journal of Operations Research, Computers & Industry, Operations Research, and other scientific outlets. In general, the studies tend to focus on the hard factors of disassembly, relate to operational issues of remanufacturers and lack of strategic perspective. The general attributes of products that support disassembly for remanufacturing are: ease of identification, ease of access, ease of handling, ease of separation and wear resistance (Sundin & Bras 2005). However, most products are designed to be disposed, not for end-of-life processing. Products that are produced in recent times are more complex, more sleeker and use more proprietary joints (Sundin et al. 2012). These all make disassembly become more difficult. A more detailed discussion about product attribute is presented below.

2.1.6.1. Product design

The time and cost to disassemble can be reduced if products are designed with ecodesign methods in mind, and this, consequently, will increase the profitability of remanufacturing companies. There are more than 150 ecodesign methods that can be used to make products more environmentally friendly (Baumann et al. 2002) without compromising other criteria, such as performance, functionality, aesthetics, quality and cost (Johansson 2002; Weenrn 1995).

Design is a critical factor in disassembly, since it determines as much as 80-90% of the reclaimed value from disassembly. Although companies can use some optimisation methods to maximise recoverability, this figure is relatively small, ranging between 10-20% (Kriwet et al. 1995). The use of modular designs, which is one of the ecodesign principles, offers flexibility during the reassembly process, as the component can be shared between different lines (Kerr & Ryan 2001). Further details on this topic can be found in Hatcher et al. (2011).

2.1.6.2.Embedded technology

The main idea of active disassembly is that products can split down by themselves. In order for this to happen, there must be an instrument embedded in the products during their development. The technology will increase the cost of production slightly, but at the end of the product's life, the cost of disassembly will be significantly lower because the products do not require extensive resources to disassemble. Embedded technology therefore offers benefits during the course of the product's life (Boks & Tempelman 1998). Active disassembly is one of the methods categorised in this technology (Chiodo & Ijomah 2012; Ijomah & Chiodo 2010) but it is currently still too expensive to be adopted for mass production (Sundin et al. 2012).

Sensor technology is another technique that assists disassembly. The technology can be used to assist data collection from critical components (Ilgin et al. 2011; Ilgin & Gupta 2011; Ilgin & Gupta 2010). Again, similar to active disassembly, which is examined in Boks & Tempelman (1998), the benefit from the sensor must be higher than the cost of development in order for the technology to be implemented. In their work, Ilgin & Gupta (2010a) demonstrate that products embedded with sensors outperform those without such technology in terms of revenue and profit.

2.1.6.3. Number of components

The number of components has an effect on the cost of disassembly (Smith & Chen 2011), as well as the sequence and level of disassembly (Johnson & Wang 1998). Using a power brake as an example, Smith and Chen (2011) included the analysis of the handling and moving of components after cores have been disassembled. They examined how the number of components affects the space that is required for handling and moving the components. In their later investigation, Smith et al. (2012) reduced the time that it took for disassembly. In both of the studies above (Smith & Chen 2011; Smith et al. 2012), there was a consistent finding that the higher the number of components, the greater the tendency to use selective disassembly, rather than complete disassembly.

2.1.6.4. Product structure

Product structure determines how cores are disassembled in a feasible sequence, because it represents how geometrically the components are designed and the assembly relationship between the components (Kuo 2000). Structure of products is related to product design (Smith et al. 2012), the number of components used (Smith & Chen, 2011) and the product's complexity (Guide et al. 2005). For this reason, the structure affects the sequence of disassembly (Smith and Chen 2011) and the disassembly time (Smith et al. 2012).

Using the disassembly sequence structure graph, Smith et al. (2012) analysed the product structure disassembly time. Product structure is related to the number of joints and both of them affect the optimum sequence and time of disassembly. Other studies examine the effect that product structure has in a broader perspective. For example, Guide Jr. et al. (1997) examined how product structure affects scheduling policies. In their research, Guide Jr. et al. (1997) demonstrated that product structure not only affects disassembly, but also other processes in remanufacturing, particularly reassembly. This effect is confirmed in their latter study (Guide et al. 2005). Product structure affects the remanufacturing operations in general, as it affects inventory policies, lot sizing, the Bill of Materials and the safety stocks of components.

2.1.6.5. Type of materials

The type of materials used is one of factors that determines the potential residual value of the cores. In some cases, the cost of disassembly outweighs the value of recovered components. In such cases, the products are not disassembled but they are shredded to recover the materials (Duflou et al. 2008). Furthermore, Duflou et al. (2008) demonstrated how components made of different type of materials have different release times. They also demonstrated that some materials have a higher value compared to others and are more resistant to a humid environment, so that they are more suitable for remanufacturing. Although the potential value of materials is high, in many cases companies have to adapt their disassembly processes with returned products. This is because the cores have not been considered for remanufacturing at the product development stage (Zwolinski & Brissaud 2008). This will cause an additional cost to remanufacturers, which will reduce their profitability.

2.2. Discussion and the research gap identified from the exploratory literature review

In general, it was found that an abundant number of studies have been conducted in the field of disassembly, and some of them have addressed remanufacturing in particular. However, it seems there is no study that has yet attempted to integrate all of the relevant factors by using a comprehensive analysis. As can be seen in Figure 2.1, the studies on disassembly for remanufacturing are divided into many different topics.

The exploratory analysis found that the majority of the existing research on disassembly uses a theoretical approach by utilising mathematical modelling and simulations. *Decisions in disassembly* and *product attributes* that affect disassembly are two of the most popular topics in this area. Of the three decisions made in the disassembly process – which are the level, method and sequence of disassembly – the sequence of disassembly is the most popular one in existing research. A comprehensive literature review pertaining to disassembly sequence was carried out by Lambert (2003).

Similarly, the *parameters of disassembly performance* have been discussed in many studies (Ilgin & Gupta 2011; Johnson & Wang 1998; Loomba & Nakashima 2012; Guide Jr. 2000; Gungor & Gupta 1998; Tian et al. 2012; Ferrer 2003). These topics sometimes contain environmental analysis and discuss how disassembly can contribute towards waste reduction (Tian et al. 2012). The topics of *evaluation methods* are a less popular research area compared to other topics. Nevertheless, they do have an influence on other studies, as the parameters used in the evaluation methods are modified or expanded by some researchers (Go et al. 2011).

Research that is carried out into the topics of *decisions in disassembly*, *parameters of disassembly* and *evaluation methods* have similarities in the sense that these topics deal with hard factors. Decisions in disassembly that are related to the number, sequence and level of disassembly, all deal with the hard factors of disassembly. All of these decisions are concerned with the physical features of products that are tangible. It is not surprising that definitions of disassembly focus on product attributes that are tangible only. Below are four existing definitions of disassembly that are found in the literature:

- *'Disassembly is a methodical extraction of valuable components/sub-assemblies and materials from post-used products through a series of operations.'* (Aksoy & Gupta 2010).
- *'Disassembly is a systematic method for separating a product into its constituent parts, components or other groupings.'* (Gungor & Gupta 1998).
- *'Disassembly is a methodical extraction of valuable parts/sub-assemblies and materials from discarded products through a series of operations.'* (McGovern & Gupta 2007).
- *'Disassembly is the process of the systematic removal of a subset of subassemblies and components from the original product, in a destructive or non-destructive manner.'* (Xanthopoulos & Iakovou 2009).

All the definitions above focus on *'how to separate products into components'*. As a result, there have been many pieces of research that have focused on product design because this is strongly related to the attributes of products, such as their weight, size, centre of gravity, joining method and the shape of products (Rose et al. 1998; Shu & Flowers 1999).

Another concept related to disassembly is 'disassemblability'. This was defined by Mok et al. (1997) as *'the degree of easy to disassemble'*. In this concept, the higher the disassemblability, the easier the product is to disassemble and, consequently, the lower the cost of disassembly. To assess the degree of disassemblability, Mok et al. (1997) identified variables that are presented in Table 2.1.

Table 2.1. Parameters of disassemblability

Part parameters: structural aspects			
Contact condition	Centre of gravity	Weight	Joint point
Symmetry	Grip point	Strength	Roughness
Interlocking	Joining material	Size	Rounding
Colour	Material	Shape	Tolerance
Structural aspects of products			
Product structure	Standardisation	Variant	Number of parts
Pre-process parameters			
Working space	Alignment mechanism	Degree of automation	
Disassembly information	Transport mechanism	Presence of hazards	
Inspection mechanism	Disassembly sequence		
In-process parameters			
Disassembly direction	Handling mechanism	Interference	Joining force

Source: Mok et al. (1997)

Similar to Mok et al. (1997), many other studies that investigate disassembly focus on product attributes. For example, Kroll and Carver (1999) identified that the metrics which affect disassemblability are as follows: accessibility, positioning, force and base-time. Material factors (Rose et al. 1998), such as fastening and joining methods (Shu & Flowers 1999), are among the product attributes that have been investigated and found to affect disassembly.

On the other hand, soft factors of disassembly, which are generally qualitative and intangible in nature, have received less attention. A good example of the soft factor related to product attribute is how innovative a product is (Tibben-Lembke 2002; Östlin et al. 2009). This factor is qualitative in nature and difficult to be quantified, as its measurement relies on qualitative judgements. The importance of qualitative factors escalates when investigations consider the relationships of between the factors with others. The degree of innovation interplays with other issues in disassembly, such as production volume, tooling and the potential value of reclaimed components. In addition, the human factor has often been neglected in the disassembly process (Desai & Mital 2005; Desai & Mital 2003). Optimal disassembly should integrate various factors that embrace the social and managerial aspect of disassembly, and not just the technical aspect (Desai & Mital 2003).

The degree of product innovation is important, since it affects the volume of production that eventually influences the economic feasibility of disassembly. Also, the volume of production is an important consideration in cases where the remanufacturers plan to invest a large amount of financial resources to set up an automatic disassembly facility (Franke et al. 2006). Product innovations are related to there being a greater variety of a particular product and a short product lifecycle. Thus, focusing on the hard factors of product attributes, without considering the soft factors, makes the analysis less comprehensive.

From the operations management perspective, the hard factors are concerned with day-to-day operations and a lack of strategic management perspectives. The inter-organisational relationship between OEMs and remanufacturers is part of the organisational issues that can support effective remanufacturing operations (Ijomah 2009), but it has been missed from the parameters presented above.

As mentioned in the preceding section, studies into disassembly are predominantly quantitative and use operations research. This is in line with the opinion of Guide and Van Wassenhove (2009) who explain that topics in product recovery are mostly examined by using quantitative methods. From the perspective of research philosophy, it can be said that there is a strong tendency for researchers to view this topic from a positivist research philosophy.

Most of studies in disassembly discussed above were conducted in a general context, without any specific information about what recovery method of disassembly is carried out – i.e. whether disassembly is carried for recycling, repairing or remanufacturing. Despite the discussions in existing studies above are general in nature, they are still useful in some way in the remanufacturing context. Thus, the existing studies discussed above can be used as a foundation to carry out research in disassembly for remanufacturing.

To sum up, from the exploratory literature review above, the limitations of existing research into disassembly can be summarised as follows:

- Existing studies investigate disassembly from a purely operational perspectives and lack analysis from a strategic perspective. Some of the relevant strategic issues include the cores-supplier relationships (Östlin et al. 2008), inter-organisational knowledge exchanges (Ijomah 2009) and investment in facilities (Östlin et al. 2008).
- The majority of the analysis of disassembly focuses on the 'hard' factors of the products, such as the product structure, type of materials and interrelationships between components. Existing definitions of disassembly found in the literature that consider the product attributes only (Aksoy & Gupta 2010; Gungor & Gupta 1998; McGovern & Gupta 2007; Li & Rong 2009) confirm this opinion. However, the soft factors of products such as product information (Yi et al. 2003; Ferrer & Ketzenberg 2004), the skills of the employee, human factors (Bley et al. 2004), product innovativeness (Santochi et al. 2002; Chiodo & Ijomah 2012) and the experience of the employees (Reveliotis 2007; Yeh 2012) are largely overlooked by these definitions.
- From a methodological point of view, the vast majority of studies have been conducted under a positivist paradigm by using quantitative methods. Very often, the results of mathematical modelling are valid only in situations where all the assumptions used by the given study have been met (Flynn et al. 1990).

In order to overcome these drawbacks, this study attempts to fill the research gaps by exploring disassembly from a strategic perspective, which combines both soft and hard factors and use qualitative method. This aim is in line with a statement from Bras & McIntosh (1999), who suggest that research into remanufacturing should consider not only product attributes, but also organisational characteristics and process choices.

2.3. Proposed research questions

As have been discussed, there has been lack of comprehensiveness in the definitions of disassembly (Aksoy & Gupta 2010; Gungor & Gupta 1998; McGovern & Gupta 2007; Xanthopoulos & Iakovou 2009). To address this gap, this research attempts to analyse disassembly from a broader perspective that includes soft factors and views disassembly not only from operational perspectives, but also from strategic perspectives.

The factors should be broader than those that affect existing definitions of disassembly (Aksoy & Gupta 2010; Gungor & Gupta 1998; McGovern & Gupta 2007; Xanthopoulos & Iakovou 2009), which mainly highlight product attributes. These factors should include organisational characteristics, process choices and product attributes (Bras & McIntosh 1999). More recent works that examine remanufacturing from organisational aspects discuss several issues, including managing cores suppliers relationships (Lind et al. 2014), building inter-organisational in closed-loop supply chains, and managing knowledge exchanges between OEMs and independent remanufacturers (Saavedra et al. 2013). Topics in process choices that have been covered in existing studies include automation for remanufacturing (Franke et al. 2006; Sundin et al. 2012). These themes need to be included because the success of product recovery is not only affected by product design but also operations and supply chains of the firms (Gehin et al. 2008). Therefore, the first question here is:

RQ1. What are the factors that affect disassembly for remanufacturing?

Remanufacturing companies with different characteristics will adopt different strategy to disassemble cores. A disassembly strategy which is appropriate for a company might be less appropriate for others. The adoption of the strategy contingent on a number of factors that were identified in the previous research question. Therefore, different remanufacturing companies will have different techniques and methods to compose a strategy for disassembly. For example, Ryan et al. (2011) demonstrate that the best approach to carry out disassembly for liquid crystal displays is a hybrid between manual and automated process. Seitz & Peattie (2004) found that automotive engine disassembly is carried out manually while Franke et al. (2006) suggest to adopt automatic disassembly for mobile phones. All these methods require different employee skills and other factors should also be considered such as volume of cores (Franke et al. 2006), relationship with cores suppliers (Vinodh et al. 2012) and residual value (Ryan et al. 2011). Once again, this decision should incorporate other relevant factors that have been identified in Research Question 1. This leads to the second research question:

RQ2. How do remanufacturing companies manage disassembly based on the factors affecting it?

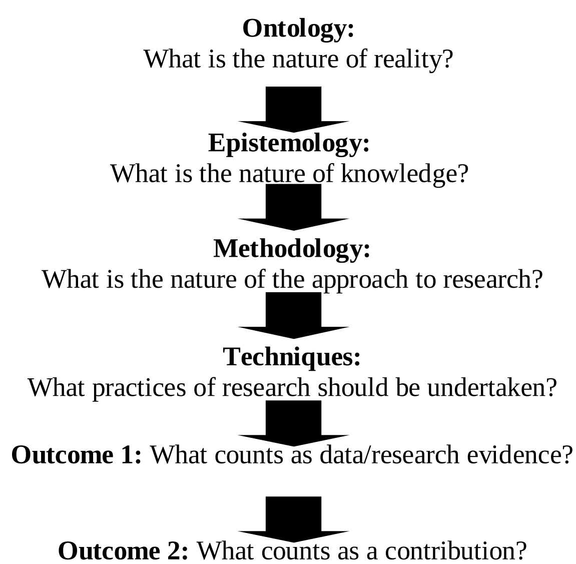
2.4. Summary of Chapter 2

This chapter attempted to analyse the existing works in disassembly by using an exploratory approach. The outcomes of this chapter were the drawbacks of existing studies, the identified research gap, the need for a new research to address this gap and research questions. The research questions have been proposed to help the researcher in selecting the appropriate research design. Chapter 3 will discuss the various options that are available to carry out the research and Chapter 4 will discuss the specific research design that will be applied in this thesis.

3. RESEARCH METHODOLOGY OVERVIEW – Focusing on case study research

This chapter aims to develop an appreciation of a wide range of methodological choices available in operations management, including an overview of various philosophical stances, research methods, and approaches to data collection and data analysis. The selection of an appropriate method and the development of a rigorous process for executing the research are important in order to produce reliable information, which eventually determines the quality of the research (Karlsson 2009).

Operations management has a diverse array of options to choose from. Methodology used in operations management fields has moved from being positivist-oriented towards being more interpretivist, using diverse methods such as direct observation, participatory, and even interpretative based on case study and interview (Craighead & Meredith 2008). This is due to the increasing influences of other disciplines that must be considered when researching in this field (Croom 2009). The issues typically require a cross-functional approach to include fields such as economics, finance, marketing and accounting. This is due to the fact that operations management is practice-oriented with a managerial character (Karlsson 2009).



Source: Anonim (2011)

Figure 3.1. Research strategy design building blocks

Considering the broad options that are available in this field, an understanding of the philosophies, research methods and techniques might help the researcher to identify which research designs might work and which might not (Easterby-Smith et al. 2012). A series of research philosophy, research methods and expected outcomes that will be discussed in this chapter are presented graphically in Figure 3.1.

3.1. Research philosophy debates

A lack of awareness of research philosophy options might not lead to research failure but it may reduce the quality of the research. Philosophical stances assist the researcher in deciding which research design is appropriate for the research – i.e. what sort of evidences are needed and how to acquire the data. They also facilitate the researcher to build new research designs that have not previously been developed, and to adapt these to existing constraints experienced by the researcher (Easterby-Smith et al. 2012).

The most common debate regarding research philosophy concerns ontology and epistemology. Ontology discusses 'the nature of reality and existence' whereas epistemology is about 'the best ways of enquiring into the nature of the world' (Easterby-Smith et al. 2012 p. 17). Both ontology and epistemology consist of two opposing paradigms with a wide range of options in between (Easterby-Smith et al. 2012; Meredith et al. 1989).

The discipline of the researcher affects the choices of philosophical stances. Researchers studying natural sciences tend to adopt a positivist philosophical approach, whilst their colleagues working in social science disciplines prefer interpretivist philosophies. However, a researcher always has a number of options, as the decision is not black and white when choosing the appropriate philosophy (Croom 2009). An understanding of the differences between the contrasting philosophies is a good step to start with, and this will be achieved in the next four sections.

3.2. Ontology

The choice of ontology is a key decision for the researcher before he moves forward to other decisions such as epistemological choices, research methods and techniques. The choice of ontology determines how the researcher views the world and interprets facts obtained from investigation. Researchers working in the natural sciences tend to adopt realism, whereas those in the social sciences prefer nominalism. Realism and nominalism are extremes, however, there are two options which can be placed between them: internal realism, and relativism. All four are presented in Table 3.1.

Table 3.1. Facts and truth in different ontologies

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 viewpoint of observer.	Facts are all human creation.

Source: Easterby-Smith et al. (2012)

3.2.1. Realism/objectivism/rationalism

Realists believe that the reality is 'out there' and is independent from the researcher. The researcher can obtain the reality easily and does not have the ability to influence the truth. Proponents of realism believe that science can only move forward when the researcher investigates a subject that has a direct association with the phenomena being studied (Easterby-Smith et al. 2012). The observations of the researcher are independent of the theories that are used to explain the phenomena, and therefore the observations can be studied and manipulated according to the needs of the researcher (Meredith 1998).

3.2.2. Internal realism

Internal realists believe that scientific laws are valid and absolute. In internal realism, there is 'one truth' but it is almost impossible for the researcher to obtain all the facts within that truth. The internal realist also believes that scientific laws can emerge independently without intervention from the researcher. Even though a complete set of facts cannot be captured by the researchers, the scientific findings are absolute and free from the researchers' interference (Easterby-Smith et al. 2012).

Even though the internal realist believes that the truth exists, it is ambiguous because it also contains ontology derived from nominalism. Consequently, the researcher who adopts internal realism will not be able to reveal all relevant data instantly. Rather, it requires the researcher to discover the findings by an active process of obtaining the facts from the field and then interpreting them to build the 'truth' (Easterby-Smith et al. 2012).

3.2.3. Relativism

The position of relativism is in between realism and nominalism, the latter being more dominant than the former. Relativism advocates that scientific laws are the result of a consensus among people interested in the phenomena. The truth is a result of human creation, which is used as a means of influencing others. The degree of acceptance of a perspective varies from person to person, depending on various factors such as social status, past reputation and credibility. Accordingly, the influence of social status is important in determining the success of certain people. Using the 'power' that they have, people from certain groups can influence the truth for their own purposes (Easterby-Smith et al. 2012).

3.2.4. Nominalism/subjectivism

Social sciences that mainly investigate the behaviour of people typically adopt nominalism. In this ontology, there is no single truth; it is the people's point of view that develops the truths (Easterby-Smith et al. 2012). The norms, values and behaviour that are prevalent in society influence how the 'truth' is shaped. Thus, among the four options of ontology, nominalism is the least suitable for studies in natural science but it is preferred for research in social science particularly those who examine human behaviour.

3.3. Epistemology

Epistemology deals with the researcher's assumptions according to how he interacts with the world (Easterby-Smith et al. 2012). The two polar positions of epistemology are positivism and interpretivism/social constructivism. More recent epistemologies that have emerged include critical realism, critical theory, hermeneutics and postmodernism, and whilst these are independent from positivism and interpretivism, they can be compared to the two polar extremes in order to identify their own positions.

3.3.1. Positivism versus interpretivism/social constructivism

As presented in the beginning of this chapter, epistemologies deal with assumptions made by the researchers when they investigate the subjects. Generally speaking, epistemologies can be categorised as positivism and interpretivism/social constructionism (Easterby-Smith et al. 2012). The positivist's view is that the phenomenon is independent from the researcher and its properties should be measured objectively without being affected by the personal beliefs and interests of the investigator. Properties of the subjects should be measured quantitatively and, to enable a better understanding, the problem should be simplified into its smallest element. In short, Crotty (1998; p. 2) explains positivism as an 'assurance of unambiguous and accurate knowledge of the world'.

Interpretivists, who occupy the opposite extreme, believe that reality is not independent from society; rather, reality is constructed by people, who contribute a certain meaning or association toward the phenomena. Researchers who utilise this epistemology do not focus on the facts that are available to them; rather, they highlight the process of giving meanings toward certain things, such as the way people communicate and interact (Easterby-Smith et al. 2012; p. 24-25). A summary of implications of different epistemologies are presented in Table 3.2 below.

Table 3.2. Comparison of positivism and interpretivism/social constructionism

Features	Positivism	Interpretivism/social constructionism
Position of observer	Independent from object	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 situation
Research progress 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 simplest terms	May include the complexity of ‘whole’ situations
Generalisation	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

Source: Easterby-Smith et al. (2012)

Even though some methodologies ‘belong’ to certain epistemology, it is not impossible for a researcher to use an epistemology from one of the extreme positions, yet to select a methodology that belong to the other position. In other words, there is no single epistemology that ascribes to all methodologies and techniques.

3.3.2. Other epistemology options

Epistemologies are like a colour spectrum from white to black with an unlimited number of colours in between. Positivism and interpretivism occupy polar positions with other epistemology options in between the two. Below, key epistemologies occupying the positions in between positivism and interpretivism are discussed.

3.4.2.1. Critical realism

Critical realism is viewed as a combination of positivism and constructionism (Easterby-Smith et al. 2012). Critical realists believe that there is a truth out there and that the investigator needs to make an effort to reveal it. Critical realism offers an advantage over positivism because it enables the researcher to identify patterns and regularities that emerge in social events (Easton 2010). In this regard, critical realism can capture phenomena that positivism might not be able to identify.

Critical realists should analyse social phenomena rather than taking them as they are. The phenomena are context dependent, and need to be understood, read and interpreted (Sayer 1992). Critical realism believes that some parts of the reality are socially constructed but some of them 'are there' (Easterby-Smith et al. 2012). Accordingly, some of the knowledge developed from social interpretation is required to interpret certain facts and evidence (Easton 2010; Johnson & Duberley 2000).

3.4.2.2. Critical theory

According to Easterby-Smith et al. (2012), critical theory was pioneered by Habermas (1978), who suggests that there should be a dialogue between interested parties to reach something that is regarded as a 'truth'. This belief is different from natural sciences in that it predominantly follows one-way communication and avoids dialogues between different parties. In natural sciences, the truth is discovered and then accepted as it is without discussions. On the contrary, in critical theory, both investigators and subjects under investigation are involved in critical dialogues to reach consensus, not only monologues. Because the truth is created by means of dialogue, influence of people who have power might affect the truth (Easterby-Smith et al. 2012).

3.4.2.3. Hermeneutics

Proponents of hermeneutics believe that the interpretation of an event should always consider the context and setting in which it occurs. They assert that context and setting give reasons as to why certain events occur, and that interpreting them without knowing the background would result in a misleading interpretation, with the consequence that there might be no single interpretation that is accepted by everyone (Easterby-Smith et al. 2012).

Hermeneutics can be applied to research into operations management, affecting the way the researcher interprets the empirical findings. For example, a researcher investigates an international manufacturing company in which production has increased but profitability has decreased during a certain financial year; the company should not be judged solely on financial performance. The condition of macroeconomics, government policy, and export and import regulation all play a part in this case. All these have to be taken into account when interpreting the events, i.e. the decrease of profitability.

3.4.2.4. Postmodernism

Postmodernism suggests that the development of science does not follow a linear pattern; rather, it is unstructured, discontinuous and unpredictable (Easterby-Smith et al. 2012). Easterby-Smith et al. (2012) use architecture to explain how the postmodern differs from the classic. Postmodern architecture is related to an experimental, heterogeneous movement, which combines various ideas and traditions. This is different from the buildings designed in the 1960s which are predominantly concrete and are gloomy colours.

Postmodernism, with its emphasis on dynamic and constant change, affects research in some ways. It is suitable for examining topics associated with organisational change, transformation and revolution. For example, in operations management research, it could be used to examine how high-tech manufacturing companies strive to survive alongside fast-paced changing technologies and fierce competition. In relation to ontology, postmodernism is in opposition with realism and more often associated with constructionism.

3.4. Review of research methods

Research methods refer to a set of techniques for data collection and analysis to investigate a specific situation (Easterby-Smith et al. 2012; Croom 2009). As has been discussed in previous sections, it is clear that a researcher who has decided to choose certain ontologies will be drawn to certain epistemologies. This brings further consequences, as certain epistemologies direct the researcher to certain methods and techniques.

To summarise the idea in the preceding paragraph, Meredith et al. (1989) propose a graph that explains the connection between research paradigm and research methods (Figure 3.2.). In addition to this, the diagram presents a framework of the interaction between data collection (how the researcher interacts with the objects) and knowledge generation. A researcher who has chosen a certain philosophical stance can use the diagram to choose from a range of possible research method options. The following sections discuss various research methods and their connection with philosophical stances, data collection techniques and analyses.

	Source and kind of information used in the research	NATURAL ⟷		ARTIFICIAL
Knowledge generation		**Direct observation of object reality**	**People's perceptions of object reality**	**Artificial reconstruction of object reality**
RATIONAL	**Axiomatic**			Reason/logic theorems Normative/descriptive modelling
↕	**Logical positivist/empiricist**	Field studies Field experiments	Structured interviewing Survey research	Prototyping Physical modelling Laboratory experiment Simulation
EXISTENTIAL	**Interpretative**	Action research Case studies	Historical analysis Delphi/expert panel Intensive interviewing Introspective reflection	Conceptual modelling

Source: adapted from Meredith et al. (1989) and Croom (2009)

Figure 3.2. Generic framework for research methods

3.4.1. Survey

Typically, survey is associated with quantitative data, but in fact it can also be used to collect qualitative data (Croom 2009). The data collected from a survey is generally descriptive and superficial in nature and due to these reasons, the survey is not the best option for examining complex phenomena. The absence of the investigator during the data collection makes the survey more objective and it is often regarded as a method that belongs to the positivist stance (Easterby-Smith et al. 2012; Meredith et al. 1989). The main drawback of this method is that the researcher might miss relevant data that require interaction. A researcher considering the use of a survey should carefully consider the design of the instrument, including issues regarding the length of the questionnaires, response rate and data quality (Croom 2009).

3.4.2. Experimental and quasi-experimental

Typically, an *experiment* examines and/or compares the behaviour of groups in a controlled situation, for example, two groups of employees in different departments. One department, referred to as the experimental group, may be given additional specific treatments whilst the other, referred to as the control group, does not receive these treatments (Croom 2009; Easterby-Smith et al. 2012). The two groups are compared to see the effectiveness of the treatments.

When the researcher has little control over the situation, *quasi-experimental* could be an alternative. In this method, the researcher accepts a real condition and modifies it to be as similar as possible to the laboratory experiment (Croom 2009). The main limitation of quasi-experimental research is that its success depends on the extent to which the researcher can control the experiment. Lack of ability to control the situation may harm the conclusion, resulting in a weak conclusion (Easterby-Smith et al. 2012).

Both experimental and quasi-experimental methods share similar characteristics in the way that they are more suited to positivism rather than interpretivism. Quasi-experiments, typically undertaken in real situations, produce more theoretical rather than managerial contributions. The contributions could be developed into hypotheses (Croom 2009) and tested to predict certain outcomes (Handfield & Melnyk 1998). This is a major step in the process of theory building.

3.4.3. Quantitative axiomatic research

Axiomatic research, also referred to as rationalist research, uses mathematical modelling as the basis to examine the behaviour of a system in a controlled situation under several scenarios (Meredith 1998). Most commonly, the primary objective of this research is to obtain an optimal solution for problems under a series of different conditions. This method has been widely used in operations management, particularly for managing the inventory system (Croom 2009). In disassembly for remanufacturing, the method has been popular in determining an optimal disassembly sequence (Lambert 2003). The main drawback of this method is that the results are only valid if the assumptions, which are often based on convenience rather than on realistic purposes, are met in real practice (Flynn et al. 1990).

Rationalism has strong connections with positivist philosophy; an emphasis on quantitative methods can offer a high precision of the variables. In addition to this, rationalist research offers better testability and reliability than qualitative methods, but this can come at the expense of developing a rigorous sampling method and a good representation of the investigated population (Meredith 1998).

3.4.4. Action research and co-operative inquiry

Adding to the six methods proposed by Croom (2009), Easterby-Smith et al. (2012) explain *action research* and *co-operative enquiry*. In social science, there has been a doubt regarding the impartiality of the researcher whose assumptions or biases may unintentionally influence the research. Action research attempts to eliminate this drawback by involving the investigator in the research process itself, minimising the gap between him and the objects being studied.

Action research starts with the belief that in order to understand a phenomenon, one should change it, and this is the objective of the action research. The researcher is actively involved in the process of change and influences the subject for the intended objective (Easterby-Smith et al. 2012). The coverage of the participants and the sustainability of the change are among the criteria used to measure the success of action research (Coughlan & Coghlan 2002).

The involvement of the investigator in the research process increases in *co-operative inquiry*. Here, the researcher and subjects of the study work together to address the research questions that have been proposed. From the perspective of the researcher the subjects are his ‘partners’. These ‘partners’ assist the researcher to identify the answers to the research question. Both action research and co-operative inquiry generally utilise rich qualitative data and are well matched with interpretivist philosophies (Easterby-Smith et al. 2012).

3.4.5. Ethnographic research

Ethnographic research requires the participation of the researcher during the study. The researcher 'immerses' within the community of subjects and becomes a part of their group. Due to the active participation of the researcher and the subjective view he therefore has, the philosophy for this method moves away from positivism and gets closer to interpretivism. This type of research would usually use a qualitative method to benefit from the richness of the collected data (Croom 2009).

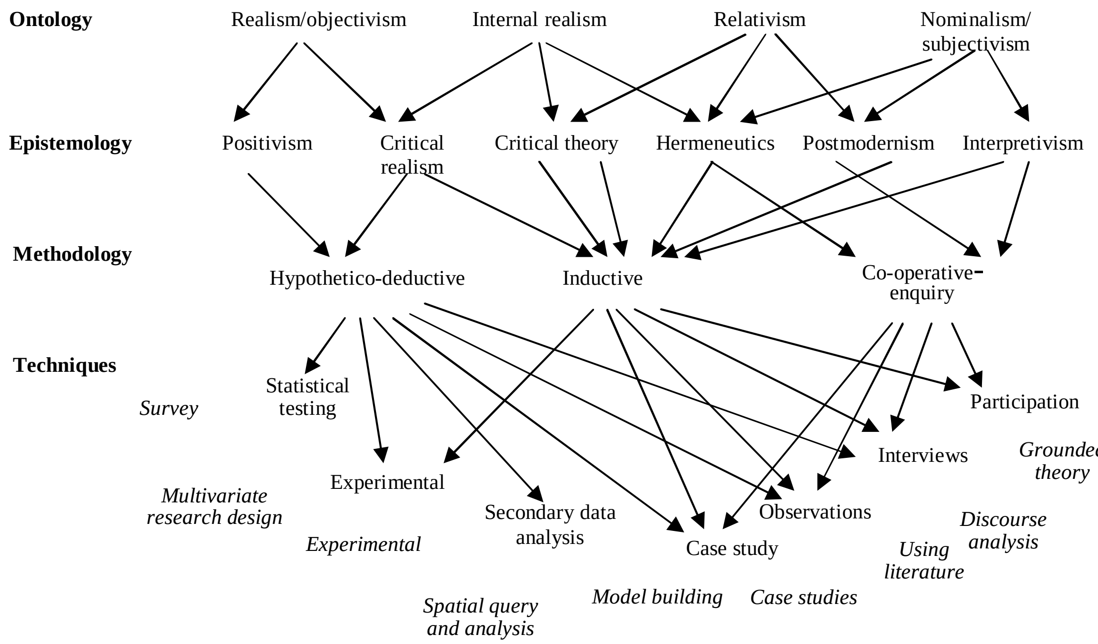
This type of study could be undertaken over a certain period to examine how the subjects evolve. In this regard, ethnographic studies are carried out longitudinally (Croom 2009). As this method accommodates subjective opinions from the researcher, it is often associated with interpretivism. Even though it is still possible to use ethnographic research in operations management, it is less likely that this method would be appropriate as this discipline has been recognised as being more suited to positivist philosophies (Meredith et al. 1989).

3.4.6. Case study

Eisenhardt (1989; p. 534) states that case study is 'a research strategy which focuses on understanding the dynamics that present within single settings'. Similarly, Yin (2009; p. 18) describes it as 'an empirical enquiry that investigates a contemporary phenomenon in depth and within real-life context'. These characteristics differ from those of experimental design in the way that it separates a phenomenon from its context. From a research philosophy perspective, case study can be used in a broad range of options, ranging from the positivist to the constructionist (Easterby-Smith et al. 2012).

3.4.7. Mapping ontology, epistemology and research methods

Discussions within this chapter have shown evidences that the decision to adopt a particular philosophy will lead to certain choices of research method and technique. Typically, researchers adopt methods that are in line with the philosophy of the research and therefore each philosophy creates its own pathway of methods and techniques as conveyed in Figure 3.3.



Source: adapted from Easterby-Smith et al. (2012) and Lynch et al. (2012)

Figure 3.3. Mapping of research design

Rather than discussing every method presented in the graph above, this chapter will focus on the case study method because this method would offer the best advantage considering the inductive nature of this study. In addition, this method has been suggested by many scholars investigating complex phenomena found in operations management field (Wacker 1998; Stuart et al. 2002; Voss et al. 2002; Meredith 1998).

3.5. Design of case study research

The research design is an 'outline' of how the research will be conducted (Yin 2011). It includes: what will be investigated, what types of data are required, where they are gathered, how to collect the data and how to conduct the analysis (Edmondson & McManus 2007). The research design should also explain how to analyse the data in order to provide answers to the research questions (Easterby-Smith et al. 2012; Yin 2009). There are a number of decisions that should be made by the researcher in a case study (Voss et al. 2002; Eisenhardt 1989; Yin 2009), including:

- Purpose of case study research
- Number of cases
- Case selection criteria
- Data collection and analysis
- Output of case study research
- How to ensure the quality of case study research

3.5.1. Purpose of case study research

In this study, disassembly for remanufacturing is viewed from an operations management perspective and requires a comprehensive perspective from different disciplines (Karlsson 2009). Case study research is well suited to this topic since this discipline is complex and is affected by many factors that may result in different interpretations (Stuart et al. 2002). If the researcher fails to include all the complex phenomena to solve practical problems, it cannot develop into a theory-building discipline (Wacker 1998).

There are several reasons why case study research is preferred in the operations management field, including a lack of theory, paucity of well-defined metrics, and complexity of problems. Case study based research is one of the best avenues to undertake investigation that contributes to a body of knowledge (Stuart et al. 2002). Without case based research, practitioners have a limited opportunity to understand knowledge. In contrast, with case research they will be able to understand a wider body of knowledge from which a theory can be implemented (Stuart et al. 2002). The summary of various purposes of research and the methodologies is presented in Table 3.3.

It is important that the researcher clarifies the purpose of the study and explains why case study has been selected. Several purposes of case studies have been identified in the literature, including to provide description, to test an existing theory, or to develop a new theory (Eisenhardt 1989; Meredith 1998; Voss et al. 2002).

Table 3.3. Matching case study research purpose and methodology

Purpose	Research question	Research structure
Exploration		
Uncover areas for research and theory development	Is there something interesting enough to justify research?	In-depth case studies Unfocused, longitudinal study
Theory building		
Identify/describe key variables Identify linkages between variables Identify 'why' these relationships exist	What are the key variables? What are the patterns or linkages between variables? Why should this relationship exist?	Few focused case studies In-depth field case studies Multi-site case studies Best-in-class case studies
Theory testing		
Test the theories developed in the previous stages Predict future outcomes	Are the theories we have generated able to survive the test of empirical data? Did we get the behaviour that was predicted by the theory or did we observe another unanticipated behaviour?	Experiment Quasi-experiment Multiple case studies Large scale sample of population
Theory extension/refinement		
To better structure the theories in light of the observed results	How generalizable is the theory? Where does the theory apply?	Experiment Quasi-experiment Case studies Large-scale sample of population

Source: adopted from Voss et al. (2002) based on Handfield and Melnyk (1998)

3.5.1.1. Exploration

Case study can be used to explore and to better understand emerging issues (Flynn et al. 1990; Meredith 1998). Normally, in a case study with this purpose, the aim is explicitly presented, for example to identify factors affecting certain processes (McCutcheon & Meredith 1993). An exploratory case study that investigates a new phenomenon requires in-depth investigations. To facilitate this purpose, a single case study is preferred (Meredith 1998).

3.5.1.2. Theory extension

This purpose is related to the generalisability of a theory developed from the case study. Proponents of positivist quantitative methods, for example axiomatic modelling or survey, claim that generalisability in case study is only valid in certain situations, so it has a narrow generalisation. On the other hand, scholars such as Meredith et al. (1989) and Yin (2009) maintain that theories developed from case study research can be used in other situations to predict different results. To extend an existing theory, the theory could be tested within a new population or in a different situation. If the theory is confirmed, the proposed theory increases in relevance and an extension might be claimed (Meredith 1998).

3.5.1.3. Theory testing

Although case study research has been widely used in theory building, particularly to examine complex constructs (Voss et al. 2002), it can also be used for theory testing (McCutcheon & Meredith 1993; Meredith 1998). Even so, the use of case study for theory testing is much less familiar because there is no guideline that is readily available for this purpose (Barratt et al. 2011). When it is used for theory testing, it is typically accompanied by other research methods, such as the survey, to allow triangulation in order to minimise the weaknesses (Voss et al. 2002).

3.5.1.4. Theory building

Using the case studies method to develop theory has been extensively discussed in the field of operations management, for example Voss et al. (2002), Meredith (1998) and McCutcheon & Meredith (1993). The use of case study to develop theory is appropriate when the topic is relatively new, there is not much empirical evidence in the field, knowledge of the problem is limited, or findings contradict common sense (Eisenhardt 1989; Voss et al. 2002).

Compared to other methods, case study is the only one that gives an insight into the answer to the question *why* (Meredith 1998; Whetten 1989; Yin 2009)*;* therefore, it provides *understanding*. Other methods, for example survey and archival analysis, do not provide the answer to the question *why* (Yin 2009). It is the *understanding* from the answers that provides the foundation to theory development (Meredith 1998). The steps of theory building using case study research are presented in Table 3.4.

Table 3.4. Process of building theory from case studies

Step	Activity	Reason
Getting started	Definition of research question	Focuses efforts
	Possibly a priori constructs	Provides better grounding of construct measures
	Neither theory nor hypotheses	Retains theoretical flexibility
Selecting cases	Specified population	Constrains extraneous variation and sharpens external validity
	Theoretical, not random, sampling	Focuses efforts on theoretically useful cases, i.e., those that replicate or extend theory by filling conceptual categories
Crafting instruments and protocols	Multiple data collection methods	Strengthens grounding of theory by triangulation of evidence
	Qualitative and quantitative data combined	Synergistic view of evidence
	Multiple investigators	Fosters divergent perspectives and strengthens grounding
Entering the field	Overlap data collection and analysis, including field notes	Speeds analyses and reveals helpful adjustments to data collection
	Flexible and opportunistic data collection methods	Allows investigators to take advantage of emergent themes and unique case feature
Analysing data	Within-case analysis	Gains familiarity with data and preliminary theory generation
	Cross-case pattern search using divergent techniques	Forces investigators to look beyond initial impressions and see evidence thru multiple lenses
Shaping hypotheses	Iterative tabulation of evidence for each construct	Sharpens construct definition, validity and measurability
	Replications, not sampling, logic across cases	Confirms, extends and sharpens theory
	Search evidence for 'why' behind relationships	Builds internal validity
Enfolding literature	Comparison with conflicting literature	Builds internal validity, raises theoretical debate and sharpens construct definitions
	Comparison with similar literature	Sharpens generalisability and raises theoretical level
Reaching closure	Theoretical saturation when possible	Ends process when marginal improvement becomes small

Source: Eisenhardt (1989)

3.5.2. Number of cases

In case study research, each case is identical to an experiment and multiple cases are identical to multiple experiments (Eisenhardt 1989). Researchers can decide to use either single case or multiple case study design. Both designs have advantages and disadvantages, which are summarised in Table 3.5.

Table 3.5. Choices of number and type of cases

Choice	Advantages	Disadvantages
Single cases	Greater depth	Limit on the generalisability of conclusions drawn. Biases such as misjudging the representativeness of a single event and exaggerating easily available data.
Multiple cases	Augment external validity, help guard against observer bias	More resources needed, less depth per case
Retrospective cases	Allow collection of data from historical events	May be difficult to determine cause and effect, participants may not recall important events
Longitudinal cases	Overcome the problems of retrospective cases	Have long elapsed time and thus may be difficult to do

Source: Voss et al. (2002; p 203)

In many circumstances, researchers prefer multiple case studies to a single case, as the former offers higher validity, reduces the tendency of observer bias and augments external validity (Eisenhardt 1989; Voss et al. 2002; Yin 2009). Multiple case studies allow the researcher to develop replication and pattern-matching using cross case analysis (Eisenhardt 1991; Yin 2009; Eisenhardt 1989; Eisenhardt & Graebner 2007).

When a researcher has decided that he will use multiple case design, the next thing to determine is how many cases are to be analysed. There are some variations regarding the number of ideal cases according to scholar; the literature explains:

- Between four and ten would be an optimal number (Eisenhardt 1989), could be used both in interpretivism and positivism
- Up to thirty cases (Yin 2009), could be used both in interpretivism and positivism
- One case or more (Stake 1995), typically used in research adopting interpretivism philosophies.

Despite the advantages of the multiple case study design, using single case study design can also offer advantages. The use of a single case study or a small number of case studies enhances the opportunity to conduct a deeper analysis and develop arguments using a rich description of a phenomenon (Siggelkow 2007) but may reduce the opportunity to find generalised patterns (Yin 2009; Voss et al. 2002; Eisenhardt 1991). The decision regarding the number of case influences the depth of the analysis and the generalisability of the results.

Yin (2009) suggests five circumstances in which a single case study design is appropriate to apply:

- to investigate a *critical* case to test a well-established theory
- to analyse an *extreme* case or a *unique* case to exploit opportunities in a rare situation
- to examine a sample that is identical with overall population; thus, the sample is selected because it is a *representative* or *typical* case.
- to investigate objects *longitudinally* over a certain period of time

Although there has been guidance from the literature as mentioned above, the final decision regarding the ideal number of cases depends on justification from the investigator. The ability to justify whether a certain number of cases is sufficient is an important skill for researchers (Voss et al. 2002); adding more cases does not always lead to better results. Adding cases is not necessary when the research has reached saturation, a condition in which incremental learning is limited (Eisenhardt 1989).

3.5.3. Case selection criteria

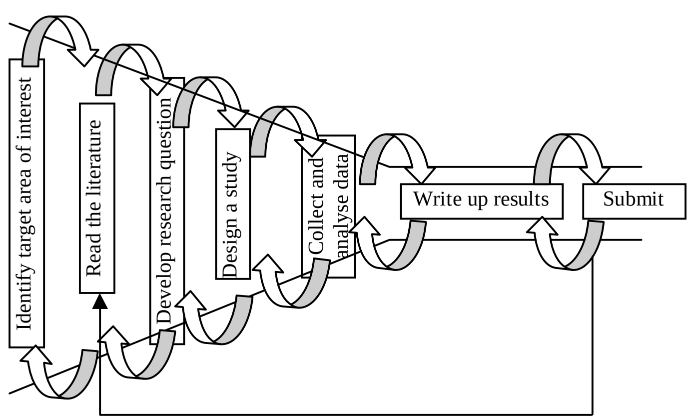
Criteria for the selection of cases in case study research are different from those in survey research. Due to the limited number of cases that can be investigated, the use of polar samples have been suggested to facilitate identification of emerging patterns (Miles & Huberman 1994; Yin 2009; Meredith 1998; Voss et al. 2002). Cases are selected based on their potential to offer a theoretical contribution, whereas in survey research, subjects are selected for the purpose of representing a population (Yin 2009).

Multiple cases are not identical to multiple respondents in survey research because survey research develops some criteria on how to select subjects to be included in a study. The objects of the samples in a survey should represent the real population upon which studies are being conducted. Conversely, the selection of subjects in case study research should consider how the new samples will contribute insights to existing subjects (Meredith 1998). In short, case study research must be based on theoretical samples whilst survey research is based on statistical samples (Yin 2009).

Of equal importance, researchers who undertake case study research need to ensure that the composition of the samples allows for direct and indirect replication. When doing multiple case studies, the composition of cases included in the study should allow researchers to develop best-fit (literal and theoretical) replication design (Yin 2009). Too many differences in the subjects may result in difficulties in identifying the emergence of similar patterns, while too many similarities lead to difficulties in conducting cross case analysis since all subjects have similar patterns (Yin 2009).

3.5.4. Data collection and analysis

Case study research is flexible, but that does not mean that it is without planning (McCutcheon & Meredith 1993). There are overlapping processes between different phases within case study research, and the researcher does not have to wait until a certain process is completed to move forward. For example, a researcher can carry out data collection and data analysis at the same time. Investigators can even change the research questions while collecting data. During the research, one usually goes back and forth between different processes, as presented in Figure 3.4.



Source: Edmondson & McManus (2007)

Figure 3.4. The process of qualitative empirical research

During the data collection process, it is not impossible to alter or add data because the case studies need to understand the phenomena as much detail as possible (Eisenhardt 1989). Yin (2009) identifies six sources of evidence with different strengths and weaknesses. These include: documentation, archival records, interviews, direct observation, participant observation and physical artefacts. These sources of evidence offer opportunities for the researcher to carry out two types of triangulation: data triangulation, and source of data triangulation (Yin 2009).

As the research progresses, the researcher can narrow down the topic and address more specific issues. This iterative process allows the researcher to perform analysis as soon as possible without losing the atmosphere of the field. In the latter processes of the study, the researcher has fewer options compared to the early stages of the research as indicated by narrower cyclical arrows in Figure 3.4 (Edmondson & McManus 2007).

Regarding data analysis, Miles & Huberman (1994) suggest a number of techniques to enable researchers to present qualitative data without reducing its meaning. At the beginning of the analysis, the researcher usually starts with a narrative description. Then, the results are combined with graphs, tables and figures after the data have been coded. The use of a combination of graphs, tables, figures and narrative description can enhance the accuracy of the analysis in comparison to using description alone.

3.5.5. Output of case study

The eventual output of the case study might be a conceptual framework, a proposition for further investigation, or possibly a midrange theory (Eisenhardt 1989; Yin 2011). A new theory emerges only if there are particular patterns within and across cases that can explain how different constructs are interrelated. Interactions between the constructs are necessary conditions in order to develop a new theory (Eisenhardt 1989). However, situations might occur where the researchers are not successful and the results of the study are merely a replication of a prior theory, or where no conclusion can be drawn due to lack of a clear pattern in the data (Eisenhardt 1989).

3.5.6. Ensuring the quality of research designs

Evaluation of qualitative research has been recognised as being more difficult than that of quantitative (Easterby-Smith et al. 2012), so it needs more explicit mechanisms. There are strategies that can be utilised in case study research to ensure that the quality is maintained, including validity evaluation (Flynn et al. 1990; Yin 2009) and the use of triangulations (Yin 2009; Easterby-Smith et al. 2002). The application of these criteria in this study will be discussed in detail in Chapter 4.

3.6. Summary of Chapter 3

An investigator needs to be aware of the full range of options available when choosing philosophies and research methods, as this decision will affect the conclusion of the research. This chapter provides an overview of various research philosophies, research methods and techniques that could potentially be applied in this research. The links between them were also discussed which was followed by a more detailed discussion on case study method, since this method will be applied in this study. The next chapter will discuss how the method is applied in this research.

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4. RESEARCH DESIGN

This chapter discusses how to execute the research in terms of philosophical options, research methods and data collection techniques, as well as how to analyse data to provide answers to the research questions. The justifications for the selection of certain options will also be discussed. All of these decisions have to be designed in such a way that the pieces of evidence collected from the field are well aligned with the proposed research questions (Yin 2009). Even if the research questions evolve during the research process (Eisenhardt 1989; Voss et al. 2002), this research design may help to define the type of organisation that needs to be contacted and narrow down the research question (Pettigrew 1990). Pitfalls, such as collecting irrelevant data, which could lead to a failure to develop a logical explanation can also be avoided (Eisenhardt & Graebner 2007; Voss et al. 2002).

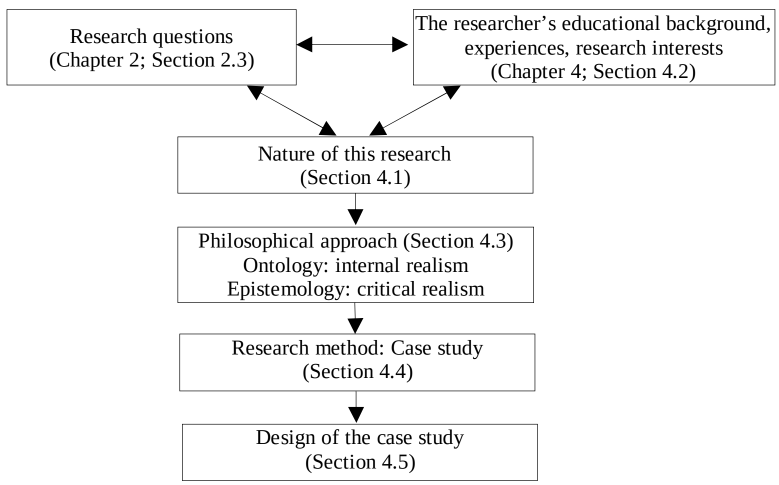


Figure 4.1. The outline of contents of this chapter

There are some considerations that need to be made when designing the research, as depicted in Figure 4.1. The research questions, the researcher's educational background, experiences and research interests, as well as the nature of the research, all affect the design of this research. These factors affect the philosophical stances of the researcher, which in turn determines the research method and design. These all will be discussed in this chapter.

4.1. Nature of the research

There is a debate about whether research philosophy or the nature of research should come first. This debate is much like the ‘chicken and egg’ phenomenon. Some academics argue that research nature should come first, while others assert that the philosophy must be the first priority. In my opinion, the two interact with one another. Research philosophy affects how the research will be carried out and the research topic determines which philosophy is suitable for conducting analysis.

This research examines disassembly for remanufacturing from a strategic operations management perspective. The study covers not only hard factors of disassembly, which are typically quantitative in nature, but also the soft factors, such as employee skills, relationships with suppliers and the degree of product innovation. As these variables are qualitative in nature, they should be viewed using the interpretivism paradigm. The consequence of including these elements is a shift in the paradigm of this topic from the extreme position of positivist to a more interpretivist approach.

If the researcher were to insist upon using purely quantitative methods, then the results of the research would not be wrong. However, difficulties would arise during the analysis, since the qualitative elements mostly deal with *why* and *how*, and therefore offer causal relationships and richness of the data (Eisenhardt & Graebner 2007; Voss et al. 2002; Eisenhardt 1989; Stuart et al. 2002). Quantitative methods do not offer these advantages, although their use may enable data to be collected more efficiently (Voss et al. 2002).

4.2. The background of the researcher

Various choices of ontology and epistemology are available to investigators; the profession and field of interest of the researcher will affect the choices of methods and techniques used to undertake the research (Davies et al. 2000). Because of this rationale, it is worth giving a brief description of the researcher's previous education and occupations here, as the researcher's background will, consciously or unconsciously, affects how he views the world.

The researcher gained both his Bachelor's and Master's degrees in management while studying at the Faculty of Business at Universitas Gadjah Mada, Indonesia. He has since served as an academic for six years in the Faculty of Economics, Universitas Islam Indonesia, in the same country. In July 2010, he began his study at the Department of Design, Manufacturing and Engineering Management, which combines both management, which tends to be interpretative in nature, and engineering, that has a more positivist element. With this background, the researcher stands between two contradictory paradigms: objective and subjective. Therefore this researcher's background is well suited to the philosophy of this study, which attempts to combine both positivist and interpretivist elements.

4.3. Philosophical approach of the research

The paradigm serves as a foundation for selecting the appropriate methodology. In other words, it gives guidance as to how the research should be executed. Studies in disassembly have been dominated with mathematical formulations belonging to the positivist view. The use of qualitative research is not popular in the field; it receives much criticism and triggers debates. Scholars have criticised the validity of qualitative research because they have looked at the study from different basic assumptions (Mangan et al. 2004). As this research is qualitative in nature, the next sections will discuss the design of the research along with the justifications. These are to ensure that the researcher adopts a rigorous research design and produces valid and reliable findings.

4.3.1. Ontology: Internal realism

This research stands in the internal realism ontology, with the aim of obtaining facts from the field objectively. In this ontology, which is closer to objective than subjective, most of the truths 'are there', but some of them require efforts by the researcher to obtain (Easterby-Smith et al. 2012). Both quantitative and qualitative data was used because disassembly is a complex phenomenon that embraces physical and non-physical elements, some of which cannot be quantified. The need to cover both physical and non-physical elements is a feature that distinguishes operations management from other management fields (Drejer et al. 2000) and internal realism is a suitable option.

This study attempts to develop a theory of disassembly strategy for remanufacturing companies, and internal realism is well suited to its purpose. The theory should contain regularities, patterns and laws that can predict causal relationships between phenomena which are found in different remanufacturers. In other words, the resulting theory developed from this study should be generalisable and applicable to different people and organisations.

Ideally, this study should develop a theory that can be applied in various organisations without any modification. Nonetheless, due to the uniqueness of every organisation, management practices need to adopt a contingency approach (Stuart et al. 2002). For this reason, minimising the proportion of required adjustment is a more plausible option.

The researcher declined subjectivist ontology because the truth that will be gathered from this approach can differ from person to person. If this study were to use subjective ontology, the output would have little relevance and the main purpose of developing a theory about disassembly strategies would be unsatisfactory. The researcher does not claim that objective ontology is better than subjective ontology. Rather, he argues that different ontologies are better suited to different studies, depending on the purpose, research problem and context of the research.

4.3.2. Epistemology: Critical realism

The main purpose of critical realism is to investigate why and how certain phenomena occur, and its main focus is the rationales behind the causalities (Johnson & Duberley 2000). This is well suited to the aim of this study, which attempts to develop a framework of disassembly strategies in remanufacturing companies. This epistemology also requires the researcher to play an active role, but with his position remaining independent from the objects of investigation.

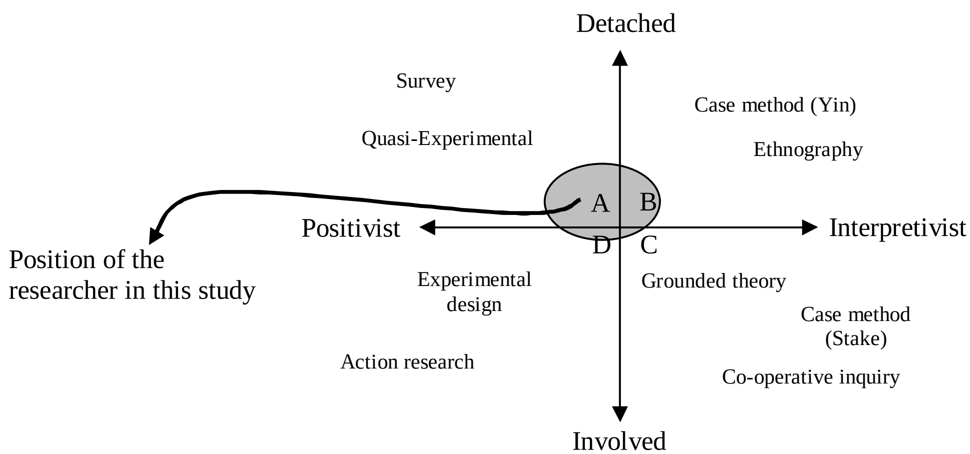
An advantage of using critical realism is that it examines both the observable and non-observable facts behind the question of why a sequence of events can occur (Easton 2010). This approach is appropriate for this research, since it deals with issues that require qualitative analysis and personal interpretation, such as employee flexibility, human skills, knowledge sharing and information sharing. In addition, the employees who perform the jobs sometimes use personal judgments to assess, sort, inspect and classify cores when they arrive at the company's facility. The researcher must take an active role to capture these types of data.

The researcher decided not to use positivism for several reasons. First, there has been an abundance of research in this topic utilising positivist ontology; this study fills a gap by undertaking research in this area by using a different ontology. Second, positivism is less appropriate for research questions in this study. Like critical realism, the purpose of positivist research is to identify patterns and regularities where managers can predict what phenomena will happen in the future in certain circumstances. But positivism is different from critical realism because it derives this approach from natural science, which neglects the existence of human interference, environmental influence and other intervening factors (Easterby-Smith et al. 2012). In other words, positivism views management practices as a physical element whose interaction can be predicted accurately. To assume that disassembly for remanufacturing practices is identical to laboratory experimentation is not realistic because it consists of not only physical elements but also human elements.

Positivism works well in research that has strict assumptions. This can only be found in entirely controlled environments, such as those in a laboratory. Social interaction that usually occurs in management practices are neglected in positivism because it only recognises explicitly presented data (Easterby-Smith et al. 2012). As a consequence, this ignorance reduces the amount of information collected from the field. Using a purely positivist paradigm carries the risk of the results being incorrect. These results could be much improved if the researcher embraces the interpretivist element as well.

4.3.3. The position of the researcher

Having discussed the ontology and epistemology, there is another decision that should be made – to what extent the researcher engages with the subject under investigation. Figure 4.2 depicts various positions that the researcher can choose from. The researcher can select any position along the continuum of the horizontal and vertical positions. It is important to stress here that, when we look at the horizontal line, there is a continuum from positivist on the left side to relativism on the right side. While on the vertical line, the researcher can choose a position from detached to involved along the continuum.



Source: adapted from Easterby-Smith et al. (2012)

Figure 4.2. Epistemology and position of the researcher

The researcher decided to be independent of, and objective towards, the research subjects. In a graph developed by Easterby-Smith et al. (2012), the position of the researcher was predominantly in above the horizontal line and slightly below the line. In this position, the researcher was independent most of the time, but sometimes needed to be involved. This was particularly the case when he dealt with qualitative data that required interpretation. The position of the researcher, which was predominantly independent, ensures that the theory developed from this research is both objective and applicable to different parties.

4.4. Methods for the research: Case study

A case study can be implemented under the epistemology of critical realism. Critical realism is suitable to use with a wide range of research methods in order to examine multi-faceted interactions between the entities in organisations. Given that the interactions of different entities in disassembly for remanufacturing are the main subjects for investigation, employing a case study under critical realism epistemology is the 'best option'. This idea is supported by Easton (2010), who explains that a case study works well using this approach because it gives reason to causality and explains why things are as they are.

When the researcher looked at the topic of this research, there were several features that drove him to use case study method. As part of operations management disciplines, the nature of the topic in this study is complex and involves an interrelationship between different factors. As a result of this characteristic, there may be more than one explanation for the research findings and a case study works well to address this issue (Stuart et al. 2002). If the researcher fails to include all of the possible explanation from the complex phenomena to solve practical problems, the study cannot be developed into a theory-building discipline (Wacker 1998).

Other method, for example survey, is less appropriate for analysing different remanufacturing companies with different contexts. Too many variables would have to be included in the survey (Stuart et al. 2002), and therefore it is not a practical way to compare different remanufacturers. In summary, a case study is the best option for this study.

4.5. Design of the case study

Research design is not merely *a plan* of how to do the research, it should also address how to *link* the empirical findings with the research questions. In this sense, the researcher needs to develop a *logical explanation* of how the empirical evidence can answer the research questions. The researcher must be careful not to become trapped in a *logistical problem* in which he collects an abundance of data, but is not successful in developing a logical explanation of the data (Yin 2009).

Yin (2009) goes further in explaining that research design is *the way how* the researcher gets to the intended location. The destination are the answers to the proposed research questions, while the starting positions are the research questions. Between the research questions and answers, there are logical reasons that *link* the two, and that is the research design. Logical explanations are important in case study research to support empirical evidences because the explanations have a lower chance of error than empirical evidence (Wacker 1998). In research design, there are a number of decisions addressed, which will be discussed in more detail in the following sections, including (Yin 2009):

- Research questions
- Propositions, if any
- Unit of analysis
- The logic explaining how the data connects to propositions
- Techniques used to interpret the data in order to answer the research questions

4.5.1. A brief review of the research questions

The research questions in this study are as follows:

1. What are the factors that affect disassembly for remanufacturing?
2. How do remanufacturing companies manage disassembly based on the factors affecting it?

Eisenhardt & Graebner (2007) state that there are two ways to justify theory development from inductive research that is based on the nature of research questions. These are theory-driven research questions and phenomenon-driven research questions. In the former, the study attempts to broaden knowledge from previous research. In this category, researchers use existing studies as foundations to develop a theoretical framework, and then apply that framework as a boundary for inductive research. Explanations and insights developed from this type of research are *strictly* confined to using existing studies as the foundation. Conversely, in phenomenon-driven research questions, researchers carry out investigations where problems have been identified in the field, but there is a lack of relevant theory. The insights and knowledge that are developed from this type of research depend on the following factors: the phenomenon's importance, to what extent the theories are relevant, and the availability of empirical findings.

Literature is predominantly the starting point of this research, so this study tends to be theory-driven, rather than phenomenon-driven. As it attempts to develop a theory, the research did not start with certain hypotheses or theories to test. The general nature of this research is inductive, although in Research Question 1 there is a deductive element in which a set of findings from literature is analysed against the empirical evidences. Developing a construct from literature is not compulsory; however, scholars suggest it is important in order to give the researcher a better direction (Voss et al., 2002; McCutcheon and Meredith, 1993). It is possible that new constructs will emerge while the study is carried out (Eisenhardt 1989), but if the priory constructs proposed at the outset are confirmed with the findings, the external validity of the research will be firmer (Barratt et al. 2011; Eisenhardt 1989). The relationship between literature review, findings from case companies and the theory's development is presented graphically in Figure 4.3.

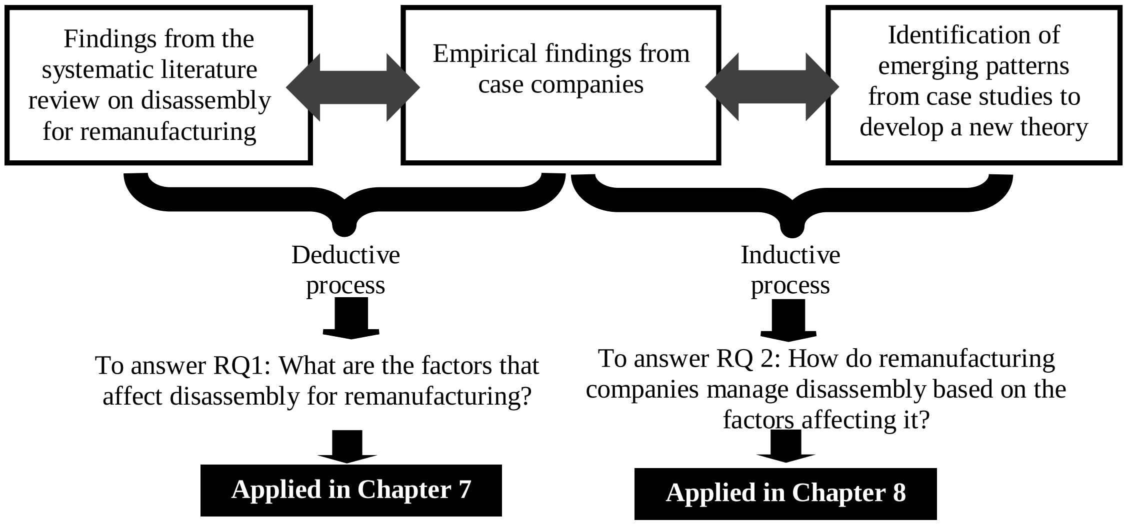


Figure 4.3. The inductive and deductive process of this research

The deductive process is typically used in quantitative research under a positivist philosophy, but this process can also be used in qualitative research (Meredith 1998; Eisenhardt & Graebner 2007). In deductive research, existing findings from current research are used to develop a conceptual framework beforehand, which is put forward before the researcher collects the data. The objective of deductive research is not to develop a new theory, but rather it is to advance a theory and to assess whether the framework proposed at the outset is confirmed or unconfirmed (Creswell 2014).

The answer to Research Question 1 was used as the foundation to answer Research Question 2. This was achieved by using an inductive process to develop a new theory by means of identifying emerging patterns. In this process, the researcher must constantly refer to the patterns and database until he succeeds in developing an established framework (Creswell 2014). The iterative process between data and proposed framework should be done continuously, until it reaches saturation (Siggelkow 2007).

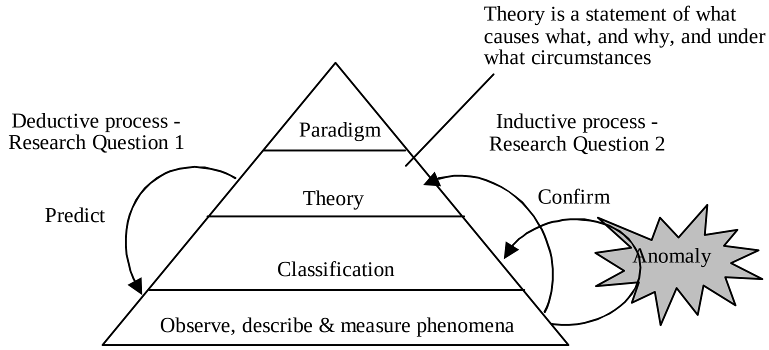
The ultimate aim of this research is to develop a theory on strategies for disassembly in remanufacturing – i.e. the answer to Research Question 2. Theory building has an advantage over theory testing in the sense that it gives a wider opportunity to collect and observe data. Theory building in field research, like in the area of operations management, is very valuable since it lacks a settled theory (Flynn et al. 1990).

4.5.2. The use of case study for inductive and deductive

Based on the description in the preceding subsection, it is clear that inductive and deductive methods should be used in this study. Deductive logic was used to answer Research Question 1, which examines whether constructs developed from the literature review were evident in case studies. On the other hand, inductive logic was used to analyse Research Question 2 that develop a new theory, based on the results of empirical analysis from Research Question 1. Hence, in this study the process of theory building was completed and formed the cycle of theory building (Christensen 2006; Christensen & Sundahl 2001).

The use of a case study to develop and test theory is appropriate since this can be used for both theory building and theory testing (Stuart et al. 2002; Meredith 1998; Eisenhardt & Graebner 2007; Voss et al. 2002), although it is less well-used in the latter. Deduction is a useful tool to recognise interesting findings from observations that can then be compared to existing theories (Christensen 2006; Eisenhardt & Graebner 2007). These comparisons help the researcher to obtain the answers to the questions *why* and *how*. If the findings from observations confirm the theory, they will make the theory stronger (Christensen 2006). However, if the findings contradict expectations, this will force the researcher to think ‘outside the box’ to find the answers. This creative thinking will lead to theory refinements. Theory development can be used to challenge current knowledge and provide justifications to amend existing views (Whetten 1989).

In certain cases, researchers find an anomaly. This is unexpected for researchers who intend to verify a theory, but for those whose purpose is to refine existing theory, an anomaly is a good stepping stone to expand their theory (Christensen 2006; Christensen & Sundahl 2001). These processes are described in Figure 4.4.



Source: Christensen & Sundahl (2001)

Figure 4.4. Process of developing a theory

4.5.3. Case study design: multiple case study

This study investigates the research question proposed at the outset by using a multiple case study analysis. From a methodological perspective, there are several reasons why this method is preferred. Case studies are appropriate when the phenomena and the context cannot be investigated separately (Yin 2009). In addition, this method is suitable for analysing questions of *why* and *how* contemporary events occur that investigators have little control over (Yin 2009; Voss et al. 2002; Meredith 1998; Stuart et al. 2002). The answers to these questions are critical elements of theory building, which this study aims to develop. Theory building for disassembly in remanufacturing from an operations management perspective is very useful due to a lack of an established theory (Flynn et al. 1990).

The purpose of using multiple cases is not to increase the sample (as might be the case when conducting a survey), but rather to increase the understanding of populations through replication (Meredith 1998; Eisenhardt 1989). A single case is often associated with constructionist epistemology, while multiple cases are more appropriate for research that belongs to objective epistemology (Easterby-Smith et al. 2012). In addition to this, the main advantage of a multiple-case study is that it can provide more compelling evidence, which will in turn result in a more robust research design (Yin 2009). This advantage is important to this research, as it attempts to build a new theory, as multiple cases will ensure that the resulting theory has a high generalisation.

Table 4.1. Details of the case companies

No.	Company, location	Number of employees	Year started remanu-facturing	Type of remanufacturers	Unit of analysis	Cores suppliers
1.	Company A, Glasgow, UK	37 people	1977	The company is an independent remanufacturer for automotive gearboxes, which also has side jobs to remanufacture marine transmissions.	Gearboxes	Individual customers, cores broker for a wide variety of brands and production years.
2.	Company B, Bristol, UK	75 people	1968	The company is a contract remanufacturer for gearboxes, automotive engines and OEMs for a small number of electricity engines. It remanufactures much more gearboxes than automotive engines.	Gearboxes	OEMs, such as BMW, Aston Martin, Mercedes Benz, Jaguar, Land Rover, etc.
3.	Company C, Rushden, UK	225 people	1973	The company was an independent remanufacturer from 1973. Then, in 2004, it was acquired by a global heavy equipment OEM and has since become a contract remanufacturer for automotive OEMs. The company also remanufactures other products, such as military products, but in smaller volumes.	Automotive engines	OEMs, such as BMW, Aston Martin, Mercedes Benz, Land Rover, Ford, Aston Martin, Perkins, etc.
4.	Company D, Glasgow, UK	43 people	1994	The company is an OEM remanufacturer for photocopiers since 2011. It was an independent remanufacturer, before being acquired by Xerox.	Photocopiers	Industrial and individual customers.
5.	Company E, Glasgow UK	625 people	1953	The company is an OEM remanufacturer for jet engines.	Jet engines	Airlines companies, governments.

4.5.4. Number of cases and cases selection

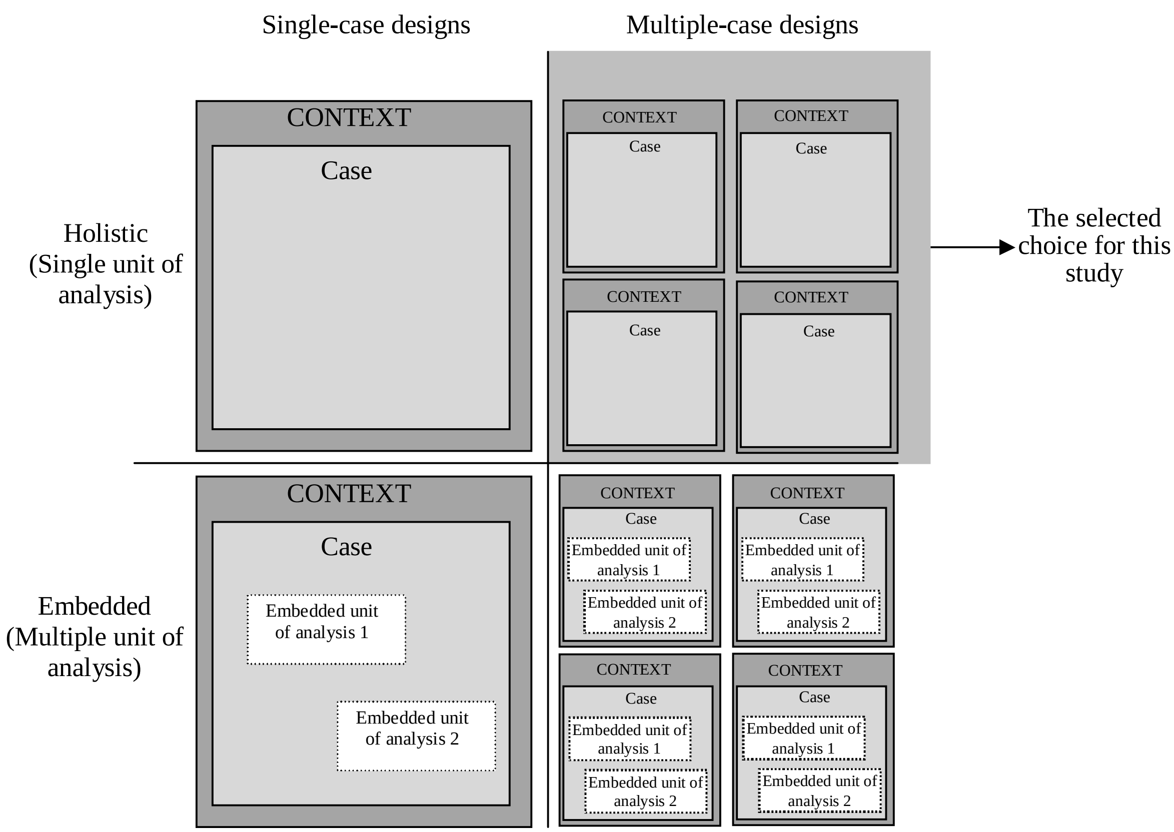
Researchers who have decided to use multiple case studies must then decide how many cases will be used. As a rule, a set amount of resources will either allow fewer cases – with greater opportunity for deeper analysis but with less opportunity to conduct replication logic between cases (Voss et al. 2002; Eisenhardt 1989) – or a high number of cases studies done in less depth. Lack of depth may make the study's results less meaningful because case studies require considerable depth to allow comparisons (Stuart et al. 2002). Thus, the researcher has to attain a balance between the *depth* and *broadness* of the study.

Five remanufacturing companies with different organisational characteristics, process choices and product attributes were selected with the purpose of allowing replication logic (Table 4.1). This figure meets the criteria proposed by Eisenhardt (1989) and Meredith (1998). Meredith (1998) suggests that between two and eight cases is the optimum number, whereas Eisenhardt (1989) recommends four to ten, arguing that this range of cases will be the most theoretically sound. When the number of cases is less than four, researchers will find it difficult to identify general patterns and build generalisation. On the other hand, if the researchers use ten or more cases they will experience difficulties to identify similar patterns amongst the cases. This is due to complexity caused by an abundant amount of data (Eisenhardt 1989).

The selection of samples is not only based on individual characteristics of the subjects, but must also consider the overall composition (Stuart et al. 2002), as the right composition enables the researcher to undertake replication logic across the cases. Following suggestions from existing works (Pettigrew 1990; Yin 2009; Graebner & Eisenhardt 2004), extreme positions or polar type remanufacturing companies were chosen to make the patterns more easily identifiable. The cases in this study are in polar positions for some key criteria, including their organisational characteristics, process choices and product attributes.

4.5.6. Holistic design of case study

Having decided the number of cases, the researcher should decide on whether to use a holistic or embedded design of case study. This study utilised a holistic case study design with a single unit of analysis for each case. In this design, multiple cases were adopted and one unit of analysis within each case was chosen. Each company had one unit of analysis and cross analysis was carried out between the companies. Given that each case company has one unit of analysis, direct replication was undertaken between companies to analyse similar situations and indirect replication to compare contrasting situations. The design is depicted graphically in Figure 4.5.



Source: Yin (2009)

Figure 4.5. Design of this case study

Characteristics that could be used for direct replication include: OEM remanufacturers (Company D and E), contract remanufacturers (Company B and C) and gearbox remanufacturers (Company B and C). On the other hand, the differences between the cases could be used for indirect replications. For example, the differences between Company A and E, which have different types of remanufacturers, could be compared. Similarly, remanufacturers that disassemble different products could also be contrasted. A list of the case companies for this study is presented in Table 4.1.

If the researcher utilises an embedded design, the analysis method will be different, and different product types that had been remanufactured will be analysed independently within each company. There is more than one unit of analysis at each study site. Data from each unit of analysis is collected separately and then analysed in parallel to find common patterns. This is different from a holistic design that needs to undertake replications across different companies.

4.5.7. Unit of analysis

Unit of analysis becomes the main focus of the investigation (Yin 2009). Although a formal statement of unit of analysis does not appear to influence the research outcome, a clear statement of it offers several advantages (Barratt et al. 2011). First, it guides researchers to select relevant literature that are related to the phenomena under investigation. Second, it helps researchers to gain a better understanding of how the phenomena are linked to existing knowledge.

The unit of analysis in this study is the product categories, as the investigation of disassembly is focused on them. In addition, the product categories determine how the resources within the organisation – e.g. human resources, technology, tools and equipment – are devoted to the task of disassembly. The arrangement of the resources determines whether the disassembly is successful or not. Thus, product categories disassembled in the investigated remanufacturing companies were the unit of analysis for this research, rather than other objects, such as companies, plants or shop floors.

Within the same product category, different brands from different OEMs share common characteristics in terms of their structure and design, and, the disassembly process can be organised in similar ways because of these similarities. Too many differences in the subjects result in difficulties in identifying similar patterns, while too many similarities leads to difficulties in identifying the most dominant patterns during cross-case analysis (Yin 2009). In addition, product categories have longer product life cycles (Tibben-Lembke 2002), compared to product models/series, so it is more feasible for them to be remanufactured.

The unit of analysis is limited to the main product categories – gearboxes, automotive engines, photocopiers and aircraft engines – that are disassembled in the investigated companies. Here, the 'main products' refers to products with the most dominant production capacity by volume. This is important to emphasise because remanufacturing companies, particularly contract and independent remanufacturers, typically carry out disassembly, and remanufacture more than one product type.

4.5.8. Data collection and triangulation

This research used both quantitative and qualitative data obtained from various data sources and utilises a qualitative method to conduct the analysis. Quantitative data used in this study includes number of productions, number of employees, number of components, and so forth. To ascertain that the collected data is objective, the researcher conducts data source triangulations (Eisenhardt 1989).

This research used content analysis for analysing empirical findings from case studies. Content analysis is a method of data analysis in which researchers attempt to identify specific words or phrases that are relevant to subject under investigation. Content analysis work well for research that has deductive element where the researchers proposed a list of specific words proposed at the outset (Easterby-Smith et al. 2012).

Data was collected from different sources, e.g. managers, supervisors and disassembly employees, with the purpose of obtaining objective data. Triangulations using different sources of data not only increase the validity of the research (Maxwell 2009; Yin 2009;

Eisenhardt 1989; Eisenhardt & Graebner 2007), but also add to the richness of the data (Eisenhardt & Graebner 2007). If there are some conflicting findings, confirmation is conducted until a consensus is agreed. Triangulations also ensure that the data collected represents the real condition of the company and avoids bias (Jick 1979). The method of triangulating the data is presented graphically in Figure 4.6.

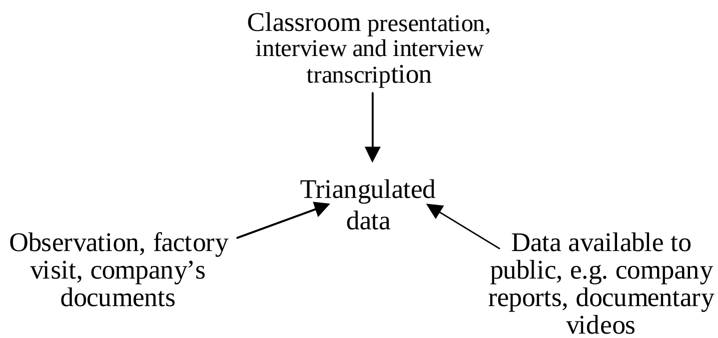


Figure 4.6. Triangulation process in this study

The researcher had initially carried out desk research to obtain external data and information that is available to the public from the case companies before he collected internal data. A good example of external data used in this study is a documentary film published by the British Broadcasting Company entitled, *'How to Build a Jumbo Jet Engine'* (King 2012). This documentary film is an excellent source of data regarding the product information of jet engines and process choices that are used to develop jet engines. A list of activities, informants and methods of collection is presented in Table 4.2.

Table 4.2. Details of data collection

Companies	Date	Method of collection	Duration	Topics addressed	Informants
Company A	22 Nov 2012	Shop floor visit Interview and discussion Observation	1 day	Remanufacturing process in general Production planning and control Disassembly process	Director Service manager Testing staff
	26 Mar 2013	Classroom presentation Discussion	2 hour	Remanufacturing process in general Managing uncertainties in disassembly	Director
Company B	13 Dec 2012	Classroom presentation Shop floor visit Observation and interview Document checks	1 day	General company information Remanufacturing process in general Production planning and control	Commercial director Disassembly shop floor staff Testing shop floor staff Reassembly shop floor staff
Company C	17 Mar 2011	Shop floor visit, classroom presentation, document checks	1 day	General company information Remanufacturing process in general Production planning and control	Build and test manager Logistic manager Quality control manager
	7 Feb 2011	Classroom presentation and discussion	1 hour 45 minutes	Organisational characteristics of remanufacturing companies	Build and test manager
	23 Apr 2012	Classroom presentation and discussion	1 h 45 min	Sorting and testing in automotive engine remanufacturing	Build and test manager
	25 Jul 2012	Interview and discussion	1 hour	Human resource issues in disassembly	Build and test manager
	9 Sep 2012	Interview	30 minutes	Product attributes, technologies for disassembly and decisions in disassembly	Build and test manager
Company D	3 Dec 2012	Shop floor visit, observation and interview Document checks	1 day	Technologies in photocopiers Human resource in remanufacturing Cores procurement.	Service manager Production manager Software engineer
	30 Jul 2013	Shop floor visit Discussion Observation	1 day	Organisational issues. Production planning and control	Service manager Production manager Disassembly employees
Company E	2 Nov 2012	Interview.	1 hour	Airline industry and regulation Engine health management system	Head of engineering
	9 Nov 2012	Presentation and discussion Observation Shop floor visit	1.5 hour	Engine induction process Production planning and control	Head of engineering Shop floor employees
	28 Nov 2012	Interview	1.5 hour	Disassembly scheduling Human resource issues	Head of engineering

4.6. Methods to ensure research quality

The quality of the research should be judged by using the paradigm under which the study is carried out (Healy & Perry 2000). A series of commonly accepted tests were employed to assess the validity and reliability of the research (Yin 2009). Validity refers to *'the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account'* (Maxwell 2009; p. 87). This was achieved through a series of assessments which are (Yin 2009; Flynn et al. 1990):

- Construct validity: ensuring that the correct concepts are being studied
- Internal validity: identifying causal relationship between concepts
- External validity: justifying the domain in which the results of the study are generalisable
- Reliability: demonstrating that the study can be repeated, producing the same results

Using the criteria above, a number of techniques were adopted to enhance the validity and reliability that is shown in Table 4.3. In the table, it can be seen that this study adopted a structured method to apply the techniques at the different stages of research, so that its validity and reliability were assured.

Table 4.3. Techniques for establishing research validity and reliability

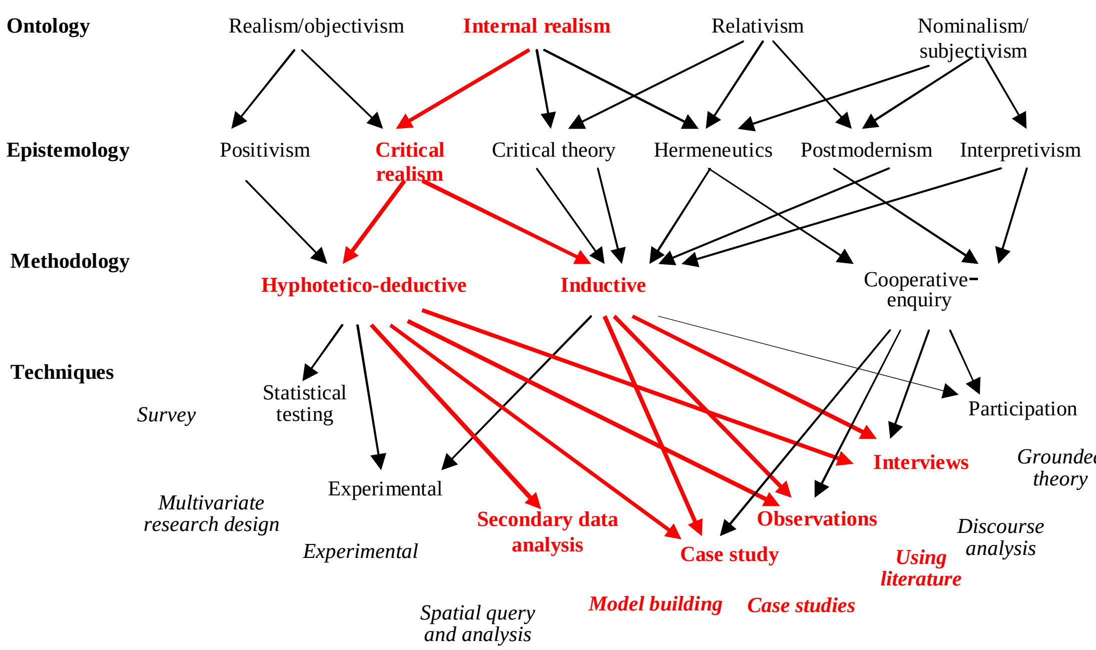
No.	Case study criteria	Case study techniques	Phase of research in which techniques occur
1.	Construct validity	Use multiple sources of evidence	Data collection
		Establish a chain of evidence	Data collection
		Have key informants review case study report	Composition
2.	Internal validity	Do pattern matching	Data analysis
		Do explanation building	Data analysis
		Address rival explanation	Data analysis
		Use logic models	Data analysis
3.	External validity	Use theory in single-case studies	Research design
		Use replication logic in multiple case studies	Research design
4.	Reliability	Use case study protocol	Data collection
		Develop case study database	Data collection

Source: Yin (2009)

4.7. Linking the philosophy, methodology and data collection

This section summarises the choices of ontology, epistemology, methods and techniques that were implemented in this study. As the ultimate objective was to develop a theory, internal realism was preferred to cover both the facts that 'are there' already, and those which need efforts from the researcher to reveal. Internal realism, which is closer to objective ontology than subjective ontology, is used to ensure that different people can apply the resulting theory in different circumstances.

Given that the nature of the subject consists of both human and physical elements, critical realism was chosen since it stands in between positivism and interpretivism. Physical elements in remanufacturing, e.g. number of cores, volume of production, number of components, are suited to positivism while human elements, e.g. employees' skills, talent and their relationship with OEMs tend to be interpretivist. Therefore, selecting critical realism can reconcile both of the contradicting elements in this research.



Source: adapted from Easterby-Smith et al. (2012) and Lynch et al. (2012)

Figure 4.7. Research design selected for this study

Finally, the researcher decided to utilise the case studies in this research, since it has some advantages over other methods. Considering this research combines deductive and inductive with elements of causal relationship, case study research offers a number of advantages, such as rich data and explanations that other methods cannot offer (Meredith 1998; Eisenhardt & Graebner 2007; Stuart et al. 2002). This is in line with the nature of operations management practice that interacts with complex factors and depends on certain settings (Stuart et al. 2002). The ontology, epistemology and methodology used in this research are displayed in Figure 4.7.

4.8. Summary of Chapter 4

The objective of this chapter was to discuss design of this study including the philosophy that is appropriate for the research questions and background of the researcher, research methods suitable for the proposed research questions, and ways of ensuring research quality. Different research philosophies have been discussed to justify why a certain philosophy was selected, while others were not chosen. The decisions were based on several considerations, including the background of the researcher, the nature of the research, the aim of the study and the research questions. To this end, using case study methods under the epistemology of critical realism is the most suitable option. In the next chapter, the researcher will conduct a systematic literature review to identify constructs. This is part of the deductive approach to identifying factors that affect disassembly.

5. UNDERSTANDING DISASSEMBLY IN REMANUFACTURING CONTEXT – A Systematic literature review

This chapter will identify factors affecting disassembly for remanufacturing, using the empirical findings of existing studies. Before analysing what factors affect disassembly for remanufacturing, it is necessary to understand *how* disassembly in the context of remanufacturing works; understanding this context is important for several reasons.

First, disassembly for remanufacturing is embedded in a series of processes within remanufacturing operations (Ijomah et al. 2007a). Thus, the success of disassembly depends on other process, and in turn also affects the success of other processes. Therefore, it is necessary to consider the interplay between disassembly and other processes during the analysis of disassembly for remanufacturing.

Second, the high level of uncertainties involved in remanufacturing operations means that traditional operations management methods are difficult to adopt (Ilgin & Gupta 2010; Junior & Filho 2012). This implies that traditional disassembly knowledge, not specifically intended to be considered in relation to remanufacturing, could be less applicable, or may even not work, in a remanufacturing context.

Third, disassembly for remanufacturing is not identical to that for other recovery methods, for example repair, reconditioning or recycling (Thierry et al. 1995). What is important here is to determine exactly how it is different.

For the reasons above, it is clear that a lack of attention to *context*, specifically regarding the type of recovery undertaken, and where the disassembly is carried out, will negatively impact upon the relevance of this study. Thus, to ensure that the study is relevant to a remanufacturing context, this chapter will pursue three objectives:

1. *To analyse how disassembly occurs in a remanufacturing context.*

First, the chapter aims to identify how disassembly for remanufacturing is embedded in a series of processes within remanufacturing operations. Some of the processes to be discussed include those that occur both prior to and following disassembly, as well as any uncertainties arising within and from these processes. When disassembly in remanufacturing can begin, and when it is categorised as finished, will also be analysed.

The result of this analysis will be a new process model of disassembly for remanufacturing. To date, no study has yet developed a process model for disassembly specifically for a remanufacturing context, covering both soft and hard factors, as well as examining disassembly from a strategic perspective. This new process model of disassembly for remanufacturing will be discussed in more detail in Section 5.3.

2. *To identify how disassembly for remanufacturing is different from that for other recovery methods.*

Here, disassembly refers to the new process model developed as a result of achieving the first objective outlined above. Using this model, it will be possible to identify the differences between disassembly for remanufacturing with that for other recovery method, for example disassembly for repair, reconditioning or recycling. These differences will be discussed in Section 5.4.

3. *To identify what factors affect disassembly for remanufacturing.*

Again, disassembly hereby refers to the new process model developed in pursuit of the first objective. To achieve this third objective, existing studies will be consulted in order to document the factors they identify as affecting disassembly; these will be presented in Section 5.5, and used as the basis for the analysis of Research Question 1. As Research Question 1 is deductive in nature, the findings of this review will be used as an a priori specification of factors affecting disassembly. Then, in Chapter 6, a priori constructs arrived at in the review will be used to analyse empirical findings, in order to explore whether these constructs do in fact manifest themselves within, and are thus relevant to, the case companies.

5.1.Literature review method

Creation of new knowledge is enabled through systematic literature reviews as a result of analysing findings from existing studies (Tranfield et al. 2003). To ensure robustness of conclusion drawn from the literature review, there are a number of criteria to determine the suitability of publications to be included in the review. As suggested by Tranfield et al. (2003), the first decision is regarding the key words used for article selection. Initially, the keyword ‘disassembl*’ and ‘dismantl*’ were entered into four databases (Emerald, ProQuest, ScienceDirect and JSTOR) to identify relevant keywords, title and abstract.

This initial literature search identified over 35,000 articles, indicating that there is an abundance of studies addressing this topic. The large quantity of existing research is not surprising, due to the general nature of the keyword used for the search. However, it is not feasible to select and study such a large number of papers; thus, a set of formal decisions were applied, which narrowed down the number of selected papers and increased the relevance of the search results.

Second, an additional keyword, 'end-of-life', was entered. The results of this second search yielded fewer results, 1,169; however, this is still too many for a systematic literature review. There are several possible end-of-life strategies, and remanufacturing is just one of them. The large number of findings yielded through a search combining the keyword 'disassembly' with 'end-of-life' are partly due to the fact that these search terms cover various end-of-life strategies, including re-use, remanufacturing, reconditioning and recycling. Thus, the researcher carried out a third search, replacing the key word 'end-of-life' with a more specific end-of-life strategy, 'remanufactur*'. As a result, the number of results was significantly decreased, to 355; this reduction convinced the researcher that a large portion of the existing research into disassembly is not specifically intended to be relevant to remanufacturing.

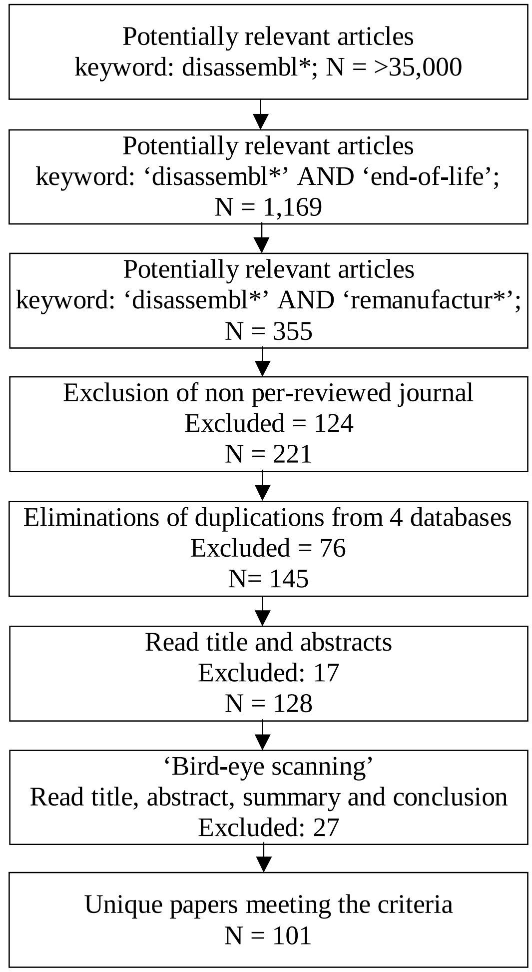


Figure 5.1. Procedures of literature selection process

In the process shown in the figure above, book chapters, magazines, and conference papers were excluded. Using this method, this article search yields only high quality peer reviewed articles, of which there were 221 papers. Next, the results from searching four databases were combined, and duplications were eliminated from the list, leaving just 145 papers, which are sourced exclusively from scientific journals.

Then, the titles and abstracts of selected papers were read in order to assess the relevance of the papers; through this process, 17 papers were excluded, leaving 128. Next, ‘Bird-eye-scanning,’ a speed-reading technique, was used to select the most suitable papers for the review; this was achieved by reading the abstract, introduction and conclusion of each paper to assess their suitability. Using this technique, 27 papers were excluded, meaning that 101 papers remained.

In selecting the papers included in our literature review inclusion/exclusion criteria was focused around papers that looked at disassembly in a remanufacturing context; that were strategic in nature and that addressed soft and/or hard factors identified earlier. As can be seen in Figure 5.1, as the keyword became narrower, and more criteria were applied, the number of findings decreased correspondingly.

To enrich the discussion, a number of papers discussing remanufacturing in general were also included because they may discuss issues that can affect disassembly directly or indirectly. These were sourced from journals relevant to the field, for example the Journal of Cleaner Production, the Journal of Remanufacturing, the International Journal of Sustainable Engineering, the Journal of Operations Management and some others.

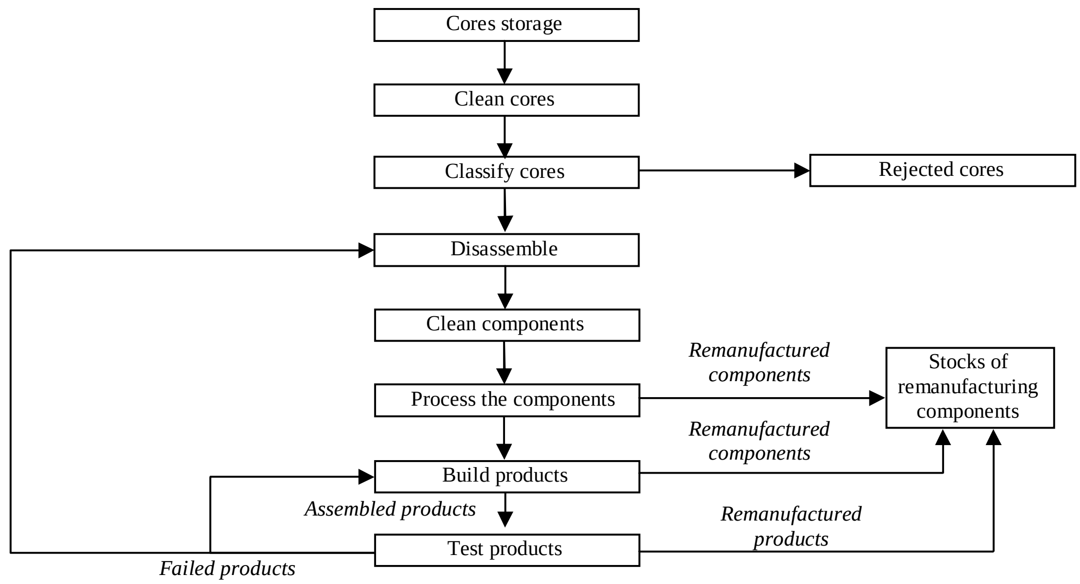
5.2. Analysis of the findings

After identifying the articles qualifying for possible review, their titles and abstracts were examined in order to assess the suitability of their content for the purpose of the review. At this stage, a brief analysis of the selected articles revealed several findings similar to those of the exploratory literature reviews presented in Chapter 2. First, from a methodological perspective, most of them use quantitative methods while the qualitative one receive much lower attention. Second, in terms of research objectives, investigation into how to achieve optimum disassembly sequence is the most popular topic. Overall, the research methods and key issues addressed in the selected articles are similar to those that were discussed in the exploratory literature review in Chapter 2.

5.3. Toward a new process model of disassembly in remanufacturing

5.3.1. A general overview on disassembly in remanufacturing process

Disassembly in the context of remanufacturing is embedded in a series of processes that are interrelated. Understanding of the *context of remanufacturing* as the foundation to develop a new process model of disassembly is important because assuming disassembly as an independent process will make the research into the topic less relevant. The position of disassembly within the process of remanufacturing is presented in Figure 5.2.



Adapted from Ijomah et al. (2007a)

Figure 5.2. Process of remanufacturing

Uncertainties are frequently mentioned as the main issue in every process of remanufacturing (Ilgin & Gupta 2010). The uncertainties in disassembly can be divided into three different types. These are: the uncertainties that exist prior to disassembly, the uncertainties that happen during disassembly and the uncertainties found in other processes after disassembly – presented in Table 5.1. These uncertainties interplay with one another, and any failure to understand how these uncertainties interrelate would make research into disassembly for remanufacturing less relevant. The use of qualitative method and put disassembly within a series of processes in remanufacturing is one of the *uniqueness* of this study that make it different from others.

Table 5.1. Uncertainties coming to and from disassembly process

Uncertainties coming from processes prior to disassembly process	Uncertainties that happen during disassembly process	Uncertainties in other processes subsequent to disassembly process
Customer order. Uncertainty from customers involving the number and timing of orders, as well as the types of products (Kongar & Gupta 2006). ***Cores sorting.*** Cores sorting reduces uncertainty about quality, but does not reduce uncertainty about quantity. Thus, cores sorting creates uncertainty in terms of the numbers of cores that are qualified for disassembly (Loomba & Nakashima 2012). ***Supply of cores***. The uncertainties predominantly come from outside remanufacturers. These include the type of cores, the quality and quantity of cores, as well as the time of arrival. These uncertainties affect almost all of the processes in remanufacturing (Jayaraman 2006; Lind et al. 2014).	***The level of optimum disassembly***. The optimum level of disassembly that should be carried out is uncertain (Lee et al. 2010). ***Number of cores to disassemble.*** This decision is related to product rebuild (Ferrer & Whybark 2001) and the optimisation of the holding costs of disassembled components (Li & Rong 2009). ***The sequence of disassembly***. The purpose of this decision is to obtain the sequence with the lowest cost (Smith et al. 2012; Smith & Chen 2011). ***Which parts should be taken out and which should not***. This decision aims to optimise the cost of disassembly (Desai & Mital 2003), particularly in the cases of selective and partial disassembly. ***What recovery method that is suitable for disassembled components***. There is a need to justify as to whether some components can still feasibly be remanufactured, otherwise they will be recycled (Vadde et al. 2011). ***Disassembly yield***. How much recovered value from the cores would be gained. Early yield information that can be gained from disassembly reduces the dependency on new components (Ferrer 2003).	***Purchasing of new parts***. What parts to order, how many and how long the lead time is (Ferrer 2003; Ferrer & Ketzenberg 2004). These decisions rely on the results gathered from disassembly. ***Product rebuild.*** There is a need to match parts from disassembly, the inventory and new parts from suppliers (Ferrer & Ketzenberg 2004; Ferrer & Whybark 2001). ***Routing of each part during testing, cleaning and reprocessing.*** Each disassembled component requires different routes for reworking and reprocessing (Guide Jr. 2000). ***Product costing and selling price.*** The cost of products (Ferrer & Ketzenberg 2004) and their selling prices (Wu 2013; Wu 2012; Vadde et al. 2011) depends on the recovery rates of the disassembly. ***Number of inventory.*** This involves an inventory of disassembled components (Tang et al. 2007; Ferrer & Ketzenberg 2004) and remanufactured products (DePuy et al. 2007).

As shown in Table 5.1 above, there are many uncertainties involved in the disassembly process, yet information coming to and from the disassembly shop floor can be used to reduce these uncertainties, and thus improve the disassembly process, for example, information coming into the shop floor can enable a shorter set-up time (Kim et al. 2006), or a more efficient disassembly sequence (Lee et al. 2010). On the other hand, information coming out of the disassembly shop floor is useful for helping to manage the number (Ferrer 2003) and lead time of new parts procurement (Ferrer 2003; Ferrer & Ketzenberg 2004). Thus, disassembly for remanufacturing not only deals with the 'physical activities' involved in breaking down products into components, but also with 'soft' factors, such as information sharing and coordination with other shop floors.

5.3.2. The new process model of disassembly for remanufacturing

As has been described in previous section, disassembly in remanufacturing interplays with other processes. Thus there is a need to develop a new process model which includes the interplay of disassembly with other processes in remanufacturing. The new process model of disassembly, illustrated in Figure 5.3 is divided into three phases. These are: *pre-disassembly activities*, *physical disassembly activities* and *post-disassembly activities*. In the new model, disassembly starts with the acceptance of cores information – i.e. when the cores will arrive, number of cores, type of cores etc. This is one of the features that distinguish this study from others.

- ***Starting point***. *Disassembly process* starts when the shop floor receives information regarding the cores, either from the sorting facilities, cores suppliers or from other departments within the company. Based on this information, the *pre-physical disassembly activities* begin, although the cores have not yet arrived in the disassembly area.

  The information regarding cores has a critical role to prepare the resources for carrying out the next steps – i.e. physical disassembly process. The preparation can avoid unnecessary cost such as idle capacity and underutilisation (Behdad et al. 2012) and therefore, remanufacturers can organise disassembly process in a more efficient way (Ondemir & Gupta 2014).

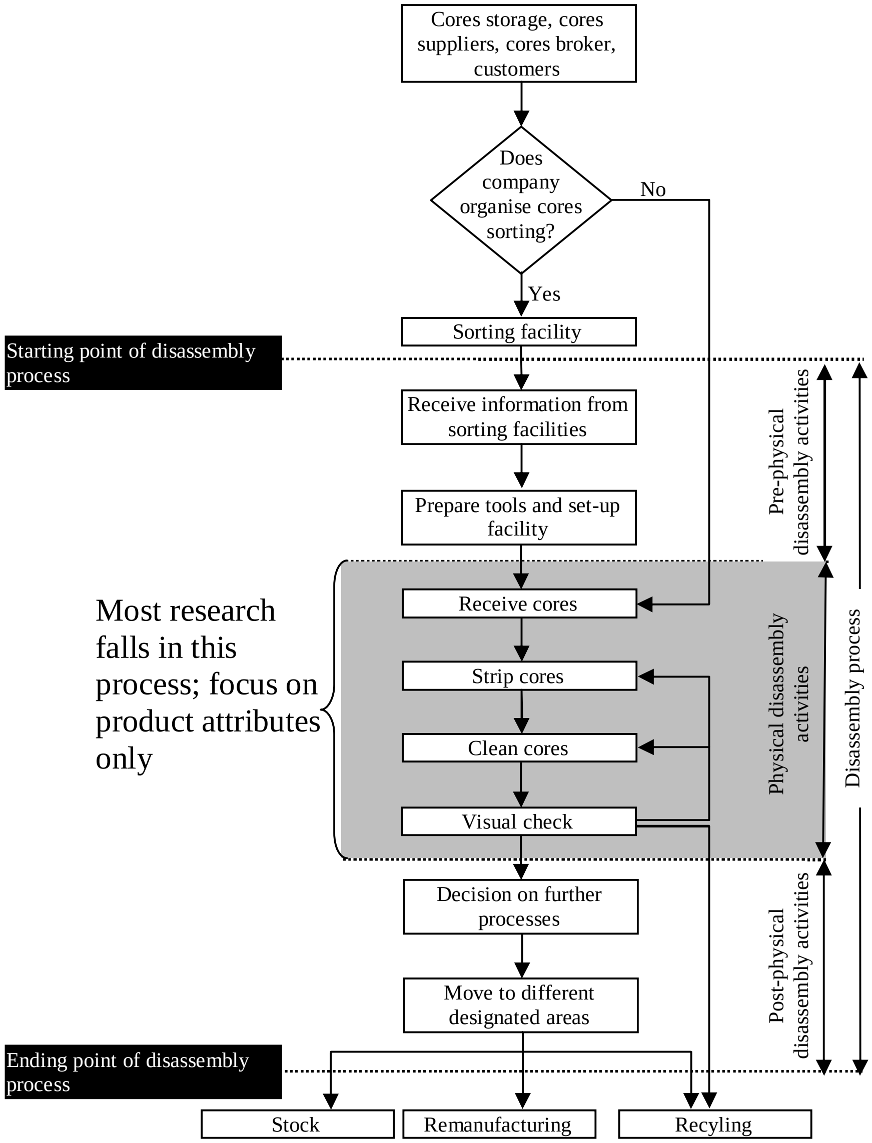


Figure 5.3. A new process model of disassembly for remanufacturing

- ***Pre-physical disassembly activities***. Once the remanufacturers receive information about the cores, the pre-disassembly process can start. Activities included in *pre-physical disassembly activities* are machinery set-up, gripping tools and the identification of joint elements (Yi et al. 2003). The arrival of cores information triggers these activities, which incur cost; on the other hand, the arrival of early core information helps remanufacturers to be more prepared so that disassembly can be undertaken more efficiently (Ferrer & Ketzenberg 2004). Remanufacturers should consider the costs that are associated with moving cores from the sorting to disassembly shop floor (Yi et al. 2003) because the improper handling of cores can cause them to be rejected (Williams et al. 2001). These costs are also assigned to the *pre-physical disassembly activities*.

- ***Physical disassembly activities.*** This stage covers the activities that are required to disconnect each part of the cores. During this phase, three decisions are made about the level, sequence and method of disassembly. At this stage, remanufacturers should make decisions such as choosing the most appropriate tools, identify the simplest disassembly mechanism and minimise the use of force (Mok et al. 1997). Sometimes employees are supported by a product database, as well as information about the history and specification of the cores, to help them to make the decisions (Westkamper et al. 1999).
- ***Post-physical disassembly activities***. Activities included in this stage are the moving and handling of disassembled components from the disassembly shop floor to the warehouse, or areas designated for other processes. During moving and handling, there might be additional costs due to component damage, the need to design customised equipment for handling the components, and the assignments of employees to do the various tasks. Other cost is associated with the time spent for carrying out the moving and handling which is varied according to weight, size and amount of the hazardous materials (Yi et al. 2003).
- ***Ending point***. *Disassembly process* is categorised as being completed when all the decisions that relate to the disassembly process have been made, disassembled components have been located to a designated area, and information that has been gathered from disassembly has been sent to other shop floors. Information that has been produced from the disassembly process includes the recovery rates of cores, the resources needed to disassemble and an estimation of the need for new parts. The information is used to determine the number of new parts that need to be ordered from suppliers, to estimate the cost of remanufacturing and the selling price of remanufactured products.

In the model presented above, there may be iterative processes between disassembly and other stages of remanufacturing, such as cleaning, testing and sorting. For example, a core is disassembled into sub-modules, then cleaned and tested. After that, it must be disassembled further into smaller components. This occurs when remanufacturers carry out partial disassembly, whereby complex products are disassembled step-by-step without a specific target as to what the final objective is.

5.4. Differences between disassembly for remanufacturing and that for other recovery methods

Several studies examine the differences between disassembly for remanufacturing and that for other recovery methods; these are presented in Table 5.2.

Table 5.2. Output and disassembly level differences across various end-of-life strategies

End-of-life strategies	Disassembly level	Main characteristics	References
Remanu-facturing	Total disasembly	Recovering the used parts and/or product. The output of the process have the same quality and warranty as a new product.	Thierry et al. (1995)
Recycling	Total disasembly	Reuse the materials from used products. The materials from used products are melted so that the identity and functionality are lost, as well as the geometry of the original product.	Thierry et al. (1995)
Repairing	Partial disassembly	The purpose is to bring back the functionality of products and only faulty components that are replaced. Warranty applies for the replaced components only.	Ijomah et al. (2007a) Thierry et al. (1995) Ijomah et al. (2004)
Recon-ditioning	Partial disassembly	Product and its components are returned to acceptable level conditions. The warranty for reconditioned products is shorter than that for a newly manufactured product. Typically it is used for technological upgrades.	Ijomah et al. (2004) Thierry et al. (1995)

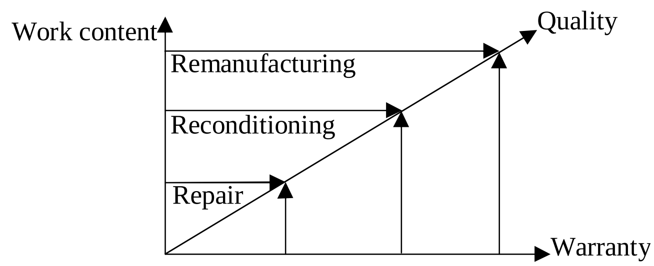
Source: Saavedra et al. (2013)

From the perspective of the new process model, the above table has several drawbacks. First, the differences highlighted focus on level of disassembly only, which is related to 'hard’ factors. By contrast, ‘soft’ factors, such as data and information about products, as well as an economic consideration of disassembly, are not discussed.

The differences above also ignore the suggestion by existing literature that disassembly can be improved using early information. For example, the development of embedded devices can provide data that can be used to support disassembly (Ilgin & Gupta 2010; Ondemir & Gupta 2014). Such technology can assist in reducing the amount of work involved in the process and, consequently, remanufacturers can carry out disassembly more efficiently (Ilgin & Gupta 2010). In addition, from a strategic perspective, developing organisational relationship with OEMs would be helpful in obtaining product specifications (Saavedra et al. 2013; Lind et al. 2014). These specifications are useful as they assist remanufacturers in preparing a facility to carry out disassembly.

Second, the studies detailed above assume that disassembly is an independent activity, ignoring the fact that disassembly in remanufacturing is related to other processes. Coordination with other processes, such as material requirement planning, bill of material and purchase of new parts should also be considered (Lee et al. 2010).

Further adding to the complexity of discussions are differences between the work content, warranty and quality of output in remanufacturing with those in repair and reconditioning (Ijomah et al. 2007). The differences between the three recovery methods, in terms of these parameters, are presented graphically in Figure 5.4. If highlighted, these differences can aid a better understanding of how disassembly for the three recovery methods is not identical.



Source: Ijomah et al. (2007)

Figure 5.4. Hierarchy of secondary production processes

Using the new process model outlined in previous sections, this section attempts to identify the differences of disassembly, from a broader perspective, for four recovery methods: remanufacturing, recycling, repair and reconditioning.

5.4.1. Comparing disassembly for remanufacturing and recycling

When distinguishing the differences between disassembly for remanufacturing and disassembly for recycling, it is important to stress the sources of the recovered value of the cores. The recovered value of cores comes from two sources: (1) the materials used to make the components, and (2) the manufacturing process which made the components. These two sources of recovered value differ in importance between remanufacturing and recycling. In remanufacturing, both sources of recovered value are important, whilst in recycling, only the value that derives from materials is considered.

Table 5.3. Differences between disassembly for remanufacturing and recycling

No.	Issues	Remanufacturing	Recycling
1.	Method to disassemble.	Destructive disassembly is not allowed.	Both destructive and non-destructive methods are possible.
2.	Priority to recover.	Consider both the value that comes from the manufacturing process and the materials to make the products.	Only considers the value of materials to make the products.
3.	Coordination of disassembly with Bill of Materials (BOM) and Material Requirement Planning (MRP).	There needs to be coordination with BOM and MRP.	There is no need for any kind of coordination, as the disassembled components are going to be melted into materials, not to be reassembled.

In recycling, companies attempt to recover the value from materials, regardless of how high the potential value from the manufacturing process is. As the condition of the components is irrelevant, the destructive method is allowed in recycling. Components made from materials with higher value will be given priority. Two components that are made from the same materials would be treated in the same way during disassembly, even if the residual value of one component was higher than the other, for example if one of the components had a higher value due to a more complex manufacturing process, complex product structure or rare component.

In remanufacturing, however, both sources of recovered value are considered. For this reason, components made from less expensive materials might be given priority, rather than components that are made from more expensive materials. This is because the former has undergone complex production processes that make the residual value higher compared to the latter one. It is the shape of the components that makes the residual value high, not the materials used to make them. Furthermore, disassembly in recycling does not produce information about the recovery rates of components and it does not require the forecasting of new parts. The summary of all the differences is presented in Table 5.3.

5.4.2. Comparing disassembly for remanufacturing and repairing

As there is a need to ensure that the output of remanufacturing is equal to, or higher than, the new ones (Thierry et al. 1995; Lund 1984; Ijomah 2008), compulsory disassembly has to be undertaken. This occurs because there are parts that must be replaced with new ones, regardless of the condition, in order to comply with legislation requirements, OEM standards or company policies. Parts are replaced because they have been identified as being typically worn out, a potential risk to the user, or have a limited amount of life remaining. In some circumstances, the parts are not necessarily replaced with new ones, but all the parts should be tested in order to ensure that they meet acceptable quality standards. In this case, the parts still have to be disassembled.

On the other hand, repairing that aims to bring back the functionality of products (Ijomah et al. 2004; Thierry et al. 1995) does not require any compulsory disassembly. Components are disassembled only if they are related to the fault of the products. There is no legislation, company policy or OEM standards that requires specific components to be replaced with new ones. Used components can be reinstalled in the products, provided that they function normally.

From an economic perspective, compulsory disassembly, which is found in remanufacturing, is not efficient, since remanufacturers have to carry out disassembles which are not always necessary (Desai & Mital 2003; Johnson & Wang 1995). Even components whose conditions are almost equal to new ones have to undergo disassembly. As a result, there might be unnecessary activities conducted by remanufacturers. In contrast, when it comes to repairing, components are only disassembled when it is necessary, for example to enable employees to carry out work on the components and restore the functionality of the products. The summary of these differences is provided in Table 5.4.

Table 5.4. Differences between disassembly for remanufacturing and repairing

No.	Issues	Remanufacturing	Repairing
1.	Compulsory to disassemble.	There are compulsory disassembly.	There is no compulsory disassembly.
2.	Economics of disassembly.	Not always economically efficient.	More efficient economically than disassembly for remanufacturing.

5.4.3. Comparing disassembly for remanufacturing and reconditioning

Remanufacturing needs a higher level of disassembly than reconditioning. This is because the resulting output of reconditioning is lower than the new products, while the output of remanufacturing is equal to or higher than the new products (Ijomah et al. 2004; Thierry et al. 1995; Ijomah et al. 2007). For this reason, remanufacturing requires more works and higher standards than reconditioning does (Ijomah et al. 2007) – see Figure 5.4. To permit more work in remanufacturing, there would have to be a higher level of disassembly than there is in reconditioning. More work in this regard refers to any remanufacturing processes, such as a more detailed inspection, more detailed testing, or a tighter criteria for sorting and inspection. On the other hand, the output of reconditioning has lower standards, which is not necessarily as strict as the criteria for new products. Disassembly for reconditioned products does not need to ensure that the quality of the resulting products is the same as new ones. There is no need to carry out disassembly, provided that the modules or parts reach acceptable quality standards.

Table 5.5. Differences between disassembly for remanufacturing and reconditioning

No.	Issues	Remanufacturing	Reconditioning
1.	Level of disassembly.	Remanufacturing has higher level than reconditioning	Reconditioning has lower level than remanufacturing.
2.	Compulsory disassembly	There are compulsory disassembly activities that should be carried out.	There is no compulsory disassembly activity that should be carried out.

As discussed previously, there are mandatory component replacements in remanufacturing. This causes compulsory disassembly, which is not always economically efficient. On the other hand, reconditioning does not need mandatory component replacements. As long as the components are still in acceptable condition, they are not disassembled. Thus, disassembly in reconditioning is only carried out whenever necessary to do. From economic perspective, this disassembly is more economically efficient than disassembly for mandatory component replacement. The summary of the difference is presented in Table 5.5.

5.5. Factors affecting disassembly in remanufacturing

Of the 101 selected articles, the researcher categorised these papers according to three major themes: organisational characteristics, process choices and product attributes. List of the selected articles are presented on the Appendix IIA. Publications that are cited on the main body text of this thesis and appear on the Appendix IIA are underlined. Then, these three overarching themes were broken down into more specific factors. As a single publication may discuss more than one factor, some publications appear more than once in Figure 5.5. The following sections will discuss how the factors identified in the literature review affect disassembly.

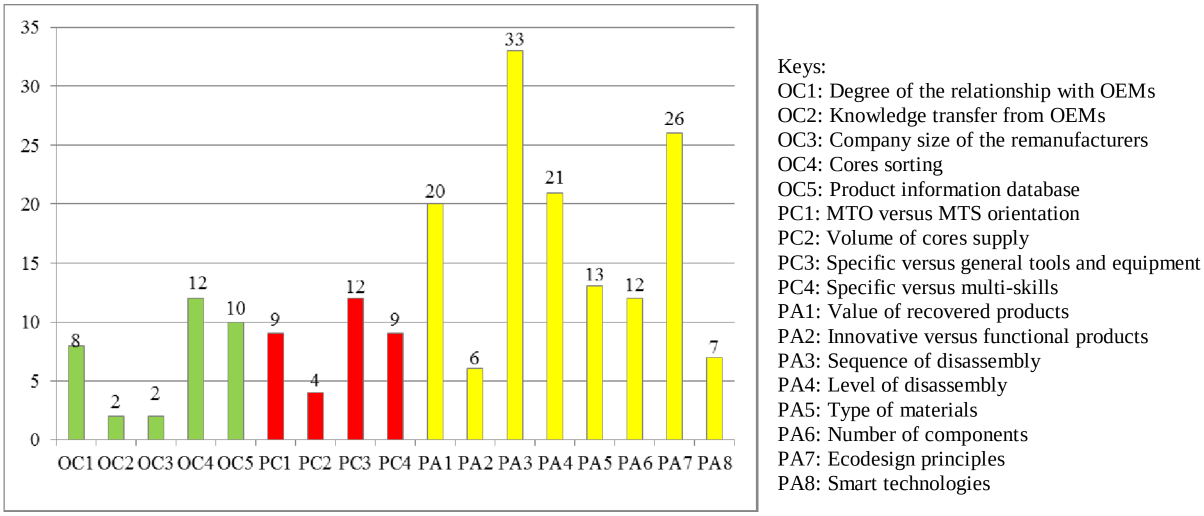


Figure 5.5. Factors affecting disassembly identified from literature review

5.5.1. Organisational characteristics (OC)

(OC1) Degree of the relationship with Original Equpment Manufacturers (OEMs)

The focus of this dimension is not only the *type* of manufacturers, for example OEMs, contract and independent remanufacturers, but also the *relationship* with the OEMs. The relationship with OEMs is important as this influences the number of cores received, which is recognised as the main constraint of remanufacturing operations (Lind et al. 2014. Meanwhile, the number of cores received affects how the remanufacturers organise disassembly. The OEM remanufacturers are more selective in the disassembly of cores and discard cores more easily. This is due to the fact that OEM remanufacturers have better access to cores, have more cores stocks (Sherwood et al. 2000) and operate a more automated process (Williams et al. 2001). These remanufacturers do not mind discarding low quality cores that might affect the performance of their automated process.

At the other extreme, independent remanufacturers, which have a lower number of cores and must purchase them, have stricter criteria for discarding the cores. Independent remanufacturers place a higher priority on saving the parts and recovering their value.

As such, cores that are discarded by the OEM remanufacturers due to quality issues might be still processed by independent remanufacturers (Sherwood et al. 2000).

(OC2) Knowledge transfer from OEMs

OEMs are able to reap some benefits from sharing product and process knowledge with contract remanufacturers (Saavedra et al. 2013). In case OEMs outsource remanufacturing activities to contract remanufacturers, the OEMs gain benefit since the information that they provide can help remanufacturers to increase recovery rates. Consequently, with the same number of cores that are sent by the OEMs to contract remanufacturers, the OEMs could receive back a larger number of recovered parts. In addition, OEMs could ask for feedback from the remanufacturers regarding product faults that might be found during disassembly, a valuable insight which could be used for design modification (Westkamper et al. 1999; Saavedra et al. 2013).

Through knowledge transfer, remanufacturers can have better access to product designs, which enables them to carry out disassembly more efficiently (Ijomah 2009; Gungor & Gupta 1998). The original product design of the OEMs is typically used to recognise the precedence relationships (Zhang et al. 2004; Tang et al. 2002). Utilising the information in the product design specification, remanufacturers can identify close to, or the most efficient disassembly sequence, which minimises cost (Smith & Chen 2011; Smith et al. 2012; Lambert 2002; Shimizu et al. 2010). The details of geometric product information is also a necessary requirement, in order to develop computerised visual sorting (Simolowo et al. 2011).

(OC3) Company size of the remanufacturers

Large and small companies have different disassembly approaches. Large companies have more automated processes, where the companies invest substantial financial resources to set up a disassembly facility. To support the automated process, the companies organise sorting of cores to discard those that might cause interruption to the material flows in disassembly (Williams et al. 2001; Simolowo et al. 2011). Damaged parts may require a long disassembly time and so affect the performance of automated disassembly; therefore these parts are less desirable (Williams et al. 2001). Large companies more resources to build relationship with OEMs as the it requires a lot of resources. The relationship can help to secure the supply of cores that typically the main problem in remanufacturing operations (Lind et al. 2014)

On the other hand, small companies typically are less automated. Disassembly is carried out by an employee who also undertakes other tasks in the remanufacturing process, from start to finish (Williams et al. 2001). As a result of this approach, the smaller companies are more flexible and so are able to adapt to small production volumes and charge premium prices to customers. This strategy does not require any stock caused by product variants like that in the OEM remanufacturers (Seitz & Peattie 2004).

(OC4) Cores sorting

Cores sorting could be used as gatekeeping to increase the homogeneity of cores quality that arrive in disassembly facility (Zikopoulos & Tagaras 2008). The sorting acts as gate keeping as cores requiring a longer time than normal to disassemble are rejected (Simolowo et al. 2011). Cores sorting require a large amount of time and cost so that some cores suppliers hesitate to do it (Lind et al. 2014). On the other hand, other companies view cores sorting as a method to reduce transportation cost. Cores are sorted in different decentralised cores collection facilities before the cores are transported to a central location (Ferrer & Whybark 2000). In case there is limited number of cores and the demand is much greater than the supply, remanufacturers still accept cores that are not sorted. In this circumstance, it is possible that the cores suppliers sell low quality cores that cannot be remanufactured and the remanufacturers have to pay the useless cores (Lind et al. 2014).

Most cores sorting is carried out manually using employee judgement. The judgment is needed to assess the difference between potential value of cores and cost of remanufacturing. The skills to make judgement, which is gained through experience, can make difference in profitability (Ferrer & Whybark 2000). An advanced method to perform cores sorting is developed by Simolowo et al. (2011). They demonstrated how automated visual analysis for sorting could reduce the disassembly cost, labour time and risk of handling hazardous materials. Although a cores sorting has been carried out to reduce uncertainties, two uncertainties remain for two reasons. First, an accurate number of items that can be recovered cannot be identified. Second, the exact number of items that can be remanufactured is still not clear even though sorting is conducted accurately (Tagaras & Zikopoulos 2008). Thus, cores sorting helps to reduce uncertainties but it cannot eliminate them.

(OC5) Product information data base

Chung & Wee (2010) demonstrate that the adoption of information technology helps to reduce the holding cost of inventory through more accurate and up to date information. Such technology also helps designers to obtain feedback from remanufacturers in order to improve the product designs to make them more environmentally friendly. The information coming from the disassembly shop floor is critical, as it clarifies the durability and reliability of the products.

Westkamper et al. (1999) point out that although disassembly is manual in nature, the use of a product information database could still be useful. A database, which stores accumulated past information, is useful give indicators regarding the state of the cores and therefore provides early information regarding which components usually need to be replaced. A product information database is typically integrated with the company information system using a standard platform, so that it can help to manage data explosion and information volumes. A product information database can provide an estimation of yield before the cores are disassembled, and so mitigate the risk of having long response suppliers. The system provides early information of components that need replacements and the company can order them as early as possible, once this information has been received. By ordering the components as soon as possible, the company mitigates the risk of having long response component suppliers. The importance of the information system increases as the yield variance increases (Ferrer 2003).

5.5.2. Process choices (PC)

(PC1) Make-to-order versus make-to-stock orientation

Broadly speaking, remanufacturing companies can be categorised according to two extreme positions. The first group consists of companies organising job shops, with repetitive tasks and complex routings. This happens within big companies that remanufacture complex cores (Ferrer & Whybark 2001). The second group consists of smaller sized remanufacturers, who disassemble more simple products like alternators, turbo chargers, starters and so forth. These plants typically organise batch production, which features many repetitive tasks and share similar routings (Ferrer & Whybark 2001).

Many studies assume that remanufacturing is conducted by small size independent remanufacturers that organise make-to-order, for example Ketzenberg et al. (2003), Tang et al. (2007) and Langella (2007). In these studies, the companies do not disassemble the products if there is no demand, and therefore the companies do not hold stock in anticipation of possible demands from customers. This is because the smaller companies typically are more able to respond to demands from the market as they arise (Ketzenberg et al. 2003; Tang et al. 2007).

In fact, many small sized companies, which are typically independent remanufacturers, are less capable of remanufacturing certain product types, particularly those with complex structures that typically have a high residual value. In many cases, OEM remanufacturers have better capability to remanufacture complex products because they have product specification. On the other hand, independent remanufacturers, which are typically small sized-companies, have much less access to product specification and consequently have difficulties to remanufacture complex products (Ferrer & Whybark 2001).

(PC2) Volume of cores supplies

Volume of cores supply have been mentioned as the biggest problem in remanufacturing. Obtaining cores at the right volume is the most important issue for remanufacturers but most companies do not get them at the right number (Lind et al. 2014). Uncertainty of the volume make it difficult to organise planning for equipment, human resource and facility (Behdad et al. 2012). The importance of cores volume is higher for complex products that have high product variety, for example photocopiers (Kerr & Ryan 2001).

A similar case is also found in mobile phone remanufacturing. Rapid new product development and life cycles of the products cause the volume of cores supplies difficult to achieve economies of scale for developing automated disassembly process. For example, Franke et al. (2006) require up to 8,000 supplies of cores per day.

High investment in the facility can offset the high cost of manual work that comes with the labour. Remanufacturers that organise disassembly manually still can gain benefits from a high volume of cores supplies. The high volume of cores supplies facilitate employee learning through job repetition and skills accumulation (Jaber & El Saadany 2011) so disassembly could be carried out more efficiently by reducing disassembly time (Reveliotis 2007).

(PC3) Specific versus general tools and equipment

There is insufficient knowledge concerning the tools that ensure the operators undertake effective works (Desai & Mital 2005). Automated disassembly is not suitable disassembly in remanufacturing due to low volume and rapid new product introductions (Sundin et al. 2012). To allow some flexibility, Ryan et al. (2011) suggest to combine automated disassembly with manual one. The flexibility of tools required for disassembly is much higher compared to those used for assembly. This is partly due to variable cores quality and models received from customers. One of the solutions to this problem is the use of intelligent tools that can be adjusted to suit various specific conditions (Westkamper et al. 1999).

Westkamper et al. (1999) state that flexible and automated disassembly could be developed for remanufacturing. The flexible method allows remanufacturers to adapt with fast changing products, processes and market situations using minimum costs (Seliger et al. 2004). Automation in disassembly could gain much benefit since more than 50% of disassembly tasks are disconnecting joints that consume more than 50% of the total disassembly time. All of these tasks are complex processes as a result of the high number of variations within the disassembly (Westkamper et al. 1999).

Low cores volume and fast change of product technology make remanufacturers hesitate to adopt automated disassembly (Sundin et al. 2012) and prefer general tools because the companies suffer a lack of prior information about the specification of the products (Zhang et al. 2004). Products that are produced in more recent times are in conflict with automated disassembly because they are more complex and more heterogeneous (Sundin et al. 2012).

(PC4) Specific versus multi skilled employees

Besides investment in customised equipment, there is a further need to acquire the skills necessary for disassembly (Gerrard & Kandlikar 2007). In the disassembly stage, the higher the level of innovation and the newness of the technology featured in the products, the higher the skills required to carry out disassembly. All of these factors reduce the ease of dissembling the products and therefore employees require a higher level of technical skill (Ijomah & Chiodo 2010).

There are job positions that may not require specific skills such as for moving and handling materials. However, other positions in remanufacturing require specific skills. The skills are available in remanufacturing companies only and typically accumulated over long-term experience as a result of the learning curve effect (Ayres et al. 1997). Given that labour cost often constitutes the main composition of the total cost (Tang et al. 2007), well-managed human resources could reduce cost and boost profitability.

Similar views are proposed by Westkamper et al. (1999), who argued that employees should be given more responsibility and job enrichment. They further suggested that disassembly tasks be combined with assembly using shared resources; this idea is that disassembly tasks are used as load levelling when the other processes have some free capacities. In order to be able to adapt to this technique, the employees should be flexible and possess a further set of different skills.

5.5.3. Product attributes (PA)

(PA1) Value of recovered products

A key requirement to achieve economic feasibility of product recovery is that there should be sufficient recovered value from disassembly process (Ryan et al. 2011). The potential value of recovered cores determines the type of recovery method that is suitable (Reveliotis 2007; Behdad et al. 2012). Also, the value of each component determines the order in which disassembly will be undertaken, as higher value components should be given higher priority as opposed to lower ones (Adenso-Díaz et al. 2008).

The quality of the components accessed through disassembly determines their potential recovered value. Damaged parts or joints are less desirable, as they hold less residual value and may also be more difficult to strip down (Gungor & Gupta 1998). In another case, remanufacturers will most probably decide not to strip down the cores, or undertake a partial disassembly to extract the high value components only. Remanufacturers will only decide to disassemble when the added value achieved by disassembling the components is at least equal to the cost of disassembly, which mostly consists of labour costs (Westkamper et al. 1999).

(PA2) Innovative versus functional products

From an economic perspective, there is little interest in the disassembly of product types that are susceptible to fast technological change (Chiodo & Ijomah 2012). This is because the fast pace of relevant technological changes requires remanufacturers to adopt new disassembly tools and equipment more frequently. They also need to attain a break-even point on the facility investment in a shorter time (Du et al. 2012). Similarly, product variety as a result of innovation is also a threat to remanufacturing. Problems resulting from product variety include the requirement for a higher number of inventories and customised parts, which results in higher operational costs than for functional products (Hu et al. 2011; Westkamper 2003).

For products with a long life, manufacturers must consider the design structure of the products, in order to support frequent disassembly. Products that have a long life, for example 10 years, require some adjustments and have to be modified in some way to suit customers' updated needs. This typically occurs within companies that offer a product service system based on a leasing agreement. Here, modularity can be used to overcome an exploding number of parts usually needed to fulfil customers' customised demands (Westkamper 2003).

(PA3) Sequence of disassembly

The purpose of disassembly sequence planning is to identify all feasible alternative sequences for stripping down cores into constituent components with correct precedence relations (Tang et al. 2002). Numerous studies investigate the sequence of remanufacturing, focusing on trying to identify the optimum sequence of disassembly, such as Kang and Hong (2012), Ma et al. (2011), Shimizu et al. (2010) and Smith et al. (2012), to name but a few. Take, for example, Smith et al. (2012) who demonstrate that the right sequence enables employees to extract selected components, so that disassembly time and expended resources can be reduced.

Typically, remanufacturers use the original product specification of the OEMs as a starting point to determine an optimum disassembly sequence. However, several factors could cause the original design to be less relevant, such as defective parts and modification by customers. Defective parts might be the result of being exposed to extreme operating conditions, accidents or unusual patterns of use. Parts that have been damaged in product use could reduce the available options for a sequence of disassembly, as some parts may require destructive disassembly (Gungor & Gupta 1998). If customers modify a product, this makes the initial disassembly sequence plan less relevant, as there will be some alteration to the product structure (Gungor & Gupta 1998; Tang et al. 2002).

Poisonous and hazardous components might also change the disassembly sequence plan. Some components may become unwanted if they are poisonous, as they could contaminate other parts, due to potential leakage or damage during disassembly; therefore, these parts should be removed as soon as possible (Adenso-Díaz et al. 2008; Gungor & Gupta 1998). As a consequence, the disassembly sequence plan must be altered in order to minimise the associated risks.

(PA4) Level of disassembly

The level of disassembly affects profitability. Complete disassembly may be the best way to minimise damage during disassembly, however, it is not always economically efficient (Smith & Chen 2011; Lambert 2002). Accordingly, finding the most optimum level is the aim that the remanufacturers attempt to achieve in order to remain competitive. Based on this analysis, a trade-off occurs between resource expense and the economic benefit obtained from disassembly (Tang et al. 2002).

Previous studies assume that disassembly for remanufacturing requires full disassembly (Guide et al. 1997) and that the remanufacturers do not incur unnecessary costs (Kerr & Ryan 2001). In real practice, these assumptions are incorrect. Not all products must undergo total disassembly for remanufacturing to be carried out, and a partial disassembly means that unnecessary costs from disassembling undesired parts can be avoided. To achieve the optimum condition, the one that minimises cost and maximises recovered value, disassembly planning and recovery decisions should be made simultaneously (Smith & Chen 2011; Adenso-Díaz et al. 2008).

The level of disassembly can also affects sequence of disassembly. Gungor and Gupta (1998) demonstrate, using a damaged flashlight as an example, that in order to extract certain parts, the initial disassembly sequence must be altered due to damaged parts. The new sequence, to attain the same level of disassembly, can be more costly than the initial prepared sequence.

(PA5) Type of materials

The materials of products determine to what extent the components can be recovered (Go et al. 2011). Plastics and aluminium are becoming more commonly used in car manufacturing, as they are lightweight (Gerrard & Kandlikar 2007). Non-durable materials are not suitable for remanufacturing (Ijomah et al. 2007) while more durable materials such as steel, iron and copper are popular for it (Westkamper et al. 1999).

By contrast, the use of toxic materials reduces how easy it is to disassemble products, regardless of their design, as most disassembly activities are manual in nature (Desai & Mital 2005). Toxic and hazardous materials can harm the operators and, consequently, disassembly may no longer be feasible technically, even though the residual value of the parts is high (McGovern & Gupta 2007). Ryan et al. (2011) demonstrate how hazardous materials from LCD should be removed so as other valuable parts can be accessed. Automated process can be a solution to overcome hazardous materials (Sundin et al. 2012).

Some parts, made of certain materials, are not suitable for remanufacturing at all. Products made of plastic, for example, are not suitable materials for remanufacturing because the quality of remanufactured products made of these materials is not equal to that of new ones. Plastic therefore can only be recycled, to be used as the material for new products, or mixed with different materials (Go et al. 2011). For this reason, it is more likely that components made of plastics will undergo a destructive disassembly than a non-destructive disassembly.

The type of materials might also alter the sequence of disassembly plan. Some components are made from different materials and are more fragile compared to others. These fragile components can be damaged if they remain inside the product when disassembly takes place. Or, in other conditions, unwanted components might be poisonous and can contaminate other parts as a result of potential leakage or damage caused during disassembly; therefore these should be removed as soon as possible (Adenso-Díaz et al. 2008).

In addition to these concerns, material composition also determines how products will be disassembled (Feldmann et al. 1999). Components made of materials that are more expensive will be assigned a higher priority compared to components made of less expensive materials. Components with high value materials also need more careful treatment whilst moving and handling during post-physical disassembly activities.

(PA6) Number of components

Products with higher number of components typically require more joints, which means they may take a longer time to disassemble. This is because, as already mentioned, more than half of disassembly tasks are the disconnecting of joints (Westkamper et al. 1999). In addition, finding the optimum disassembly sequence is made more difficult as a result of the increasing number of components (Kang & Hong 2012; Ma et al. 2011; Smith et al. 2012; Vinodh et al. 2012). Thus, a higher number of components leads to a more costly and complex disassembly process, which eventually reduces the economic viability of disassembly (Zwolinski & Brissaud 2008).

A larger number of parts necessitate a more reliable infrastructure, particularly with regard to information systems that manage part explosion. The problem of parts explosion escalates when products with a high number of parts are designed for customers with customised specifications (Westkamper 2003). A good example of this case is jet engines. Many jet engines are modified for different purposes and market sectors, for example military purposes, private jet planes, commercial airplanes, and so forth. In general, remanufacturers that disassemble products with a high number of components require higher resources for investment in information system infrastructure.

The use of an information system infrastructure is not only to manage part explosion, but also to support coordination between the disassembly and rebuild stages. This coordination is a critical requirement for the industrialisation of remanufacturing business, in order that remanufacturing can be carried out on a large scale (Westkamper 2003).

(PA7) Ecodesign principles

Products that are specifically designed for disassembly offer far greater savings than products that are not designed for such purposes (Kerr & Ryan, 2001; Chung & Wee, 2010). There are several methods identified in the literature that can support disassembly including joining methods that are disassembly friendly (Gungor 2006; Siddique & Rosen 1997; Ferrer 2001), modular design (Hu et al. 2011; Westkamper 2003; Kerr & Ryan 2001; Ferrer 2001; Adenso-Díaz et al. 2008) and standardisation to reduce part variety (Westkamper 2003; Du et al. 2012). All of these principles consistently assist disassembly in order to make it more efficient and more profitable. Güngör (2006) demonstrates that the type of connectors determines whether the components must be disassembled in destructive or non-destructive ways. Products should be designed to support over products' whole life, not a single disassembly only. This is particularly important for high value products that are managed through long term leasing agreements (Westkamper 2003).

There are several benefits of using ecodesign principles. One of the benefits is the increased ease of disassembly, which is reflected in the time required to disassemble (Du et al. 2012). When companies manage the products over their life cycles, resource reduction can be improved if the products have been designed for disassembly (Kerr and Ryan 2001). Appropriate product design can reduce material and labour cost as well as higher flexibility of sales force (Abbey et al. 2013).

Companies can face some additional costs if they adjust their remanufacturing process to existing products that have not adopted ecodesign principles (Zwolinski & Brissaud 2008). Nevertheless, from the OEMs' perspective, adoption of ecodesign is not always beneficial, as facilitating a high degree of disassembly will increase manufacturing cost and reduce the price of remanufactured products, leading to cannibalisation between new and used products (Wu 2013). The OEMs use product design as a mean to create obstacles for independent remanufacturers competing in the same market (Sundin et al. 2012).

(PA8) Smart technologies

Nowadays, many products are embedded with electronic control systems with the purpose of giving the products a ‘technical intelligence‘. The devices are connected with organisation wide IT networks, so that they can support maintenance, upgrading, reconfiguring, and managing the service (Westkamper 2003).

Most economic benefit is gained through more efficient operations, due to cost reduction in terms of labour cost, the time to identify sequence and level of disassembly, picking tools and equipment, and the need to replace damaged components during disassembly (Chiodo & Ijomah 2012). Certain conditions are required in order to adopt such technology; first, the volume of production should be adequate; second, the cost of embedding the technology should be lower than the resulting benefit (Ilgin & Gupta 2011).

5.7. Summary of Chapter 5

Following the systematic survey of literature related to analysing disassembly in a remanufacturing context, it is necessary to reflect on to what extent the purpose of the review has been fulfilled.

There are three main findings derived from the literature review. First, a new process model of disassembly for remanufacturing is developed. In the new process model, disassembly is not merely the physical activity of breaking down products into components but rather consists of a series of steps. Disassembly is thus viewed as a process, which begins when a remanufacturer receives cores information, and finishes when all decisions pertaining to disassembly have been made.

Second, the systematic literature review reveals differences between disassembly for remanufacturing and that for other recovery methods – i.e. reconditioning, repairing and recycling. These differences make up the new knowledge emerging from this study.

Third, 17 factors that affect are identified arising from the systematic literature review. 'Disassembly' hereby refers to the new process model of disassembly developed specifically for the remanufacturing context. Of the 17 factors, 5 are categorised as organisational characteristics, 4 as process choices and 8 are related to product attributes.

In the next chapter, the 17 factors identified in the systematic literature review presented in this chapter will be analysed to determine whether they manifest themselves in empirical findings.

6. CASE STUDIES

This chapter deals with within case analysis for each case as an independent entity. The steps of analysis in this chapter used guidance proposed by Yin (2011) that consist of 5 steps: compiling, disassembling, reassembling, interpreting data and drawing conclusions. The descriptions of these steps is presented in Appendix III. There is no clear boundaries between the steps but the majority of contents in this chapter is the results from disassembling, reassembling and interpreting data.

Within case analysis is introduced with case study reports that provide the overall picture of the case company. The reports, which are attached in Appendices IVA, IVB, IVC, IVD and IVE, were written based on the interviews between the researcher and the subjects, and are also based on observations and documentations. Using these reports, the researcher can be familiarised with the subjects so that the following processes can run more smoothly during analysis (Eisenhardt 1989). Based on the reports, which also function as the raw data sources, this chapter begins with a brief narrative description of each case, and the last two sections within each case will discuss the answers of the two research questions within corresponding cases.

To answer research question 1, findings from narrative analysis will be analysed further along with existing research presented in Tables 6.1, 6.2, 6.3, 6.4 and 6.5. These tables will analyse whether dimensions that have been identified to affect disassembly from the literature review are confirmed or unconfirmed. Although constructs identification from the literature review points the study in certain directions, the researcher needs to be flexible as new constructs may emerge from the cases. With such flexibility, the adoption of a new construct is possible and thereby will contribute to the originality of the theory (Eisenhardt 1989).

Sections 6.1.5, 6.2.5, 6.3.5, 6.4.5 and 6.5.5 will discuss the answer for Research Question 2 within each case using an exploratory approach. In these sections, emerging patterns from case studies will be identified. The structure of this chapter is depicted graphically in Figure 6.1.

To enable the identification of the factors affecting disassembly during the analysis, different colours are used: green represents organisational characteristics, red represents process choices, and yellow represents product attributes. The numbers in parentheses indicate the dimensions obtained from the systematic literature review in Chapter 5.

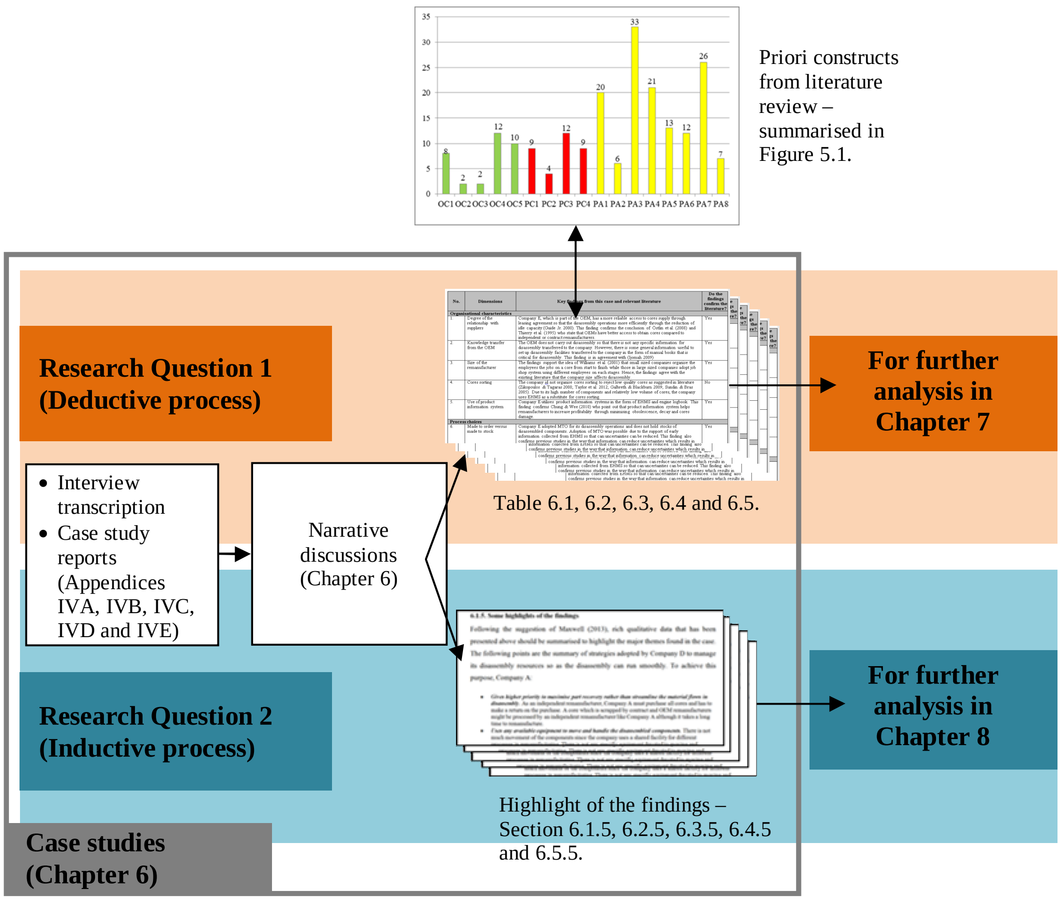


Figure 6.1. The flow of within case analysis in this chapter

6.1. Company A

Company A is an independent remanufacturing company for gearboxes that has run remanufacturing business since 1976 and remains a family business ever since. The company has 35 employees to remanufacture gearboxes that come directly from customers. Given that it is a family business that employs a small number of staffs, the working condition of the company is casual and slightly informal.

There are OEMs that previously worked with Company A, including Automatic Choice, Xpart/CAT Logistics (MG Rover), Chevrolet, Daewoo, Nissan UK, SsangYong, Subaru etc. Currently, only Hyundai maintains the relationship with the company. Company A is a dealer for Hyundai customers whose products are still in the warranty period. If there is any problem with the products, these customers do not contact Hyundai; they contact Company A and the company offers its service on behalf of Hyundai. Other than that, all other gearbox remanufacturing orders come from individual customers directly from the market.

6.1.1. Organisational characteristics (OC)

In terms of (OC1) relationship with OEMs (Original Equipment Manufacturers), Company A could be categorised as an independent remanufacturer since most of its works come directly from the market. Currently, the company has one dealership agreement with Hyundai, but the relationship does not offer much benefit to the company for a number of reasons. First, the cores come from car users, not from the company. It is the car users who make the decision whether to use the service provided by the company or not, rather than the OEM. Consequently, the dealership agreement with the OEM is less relevant to ensure the availability of the cores. Second, the cores that arrive to the company are in small volumes because they come from different individual customers. Third, the OEM does not offer (OC2) knowledge transfer regarding knowledge of remanufacturing and disassembly.

Considering its employee number, Company A is a (OC3) small sized company according to classification by the Department for Business Innovation & Skills (2014). The company employs 37 people, including administrative staff. This figure is below the 250 employee threshold for a medium sized company.

Company A does not organise (OC4) cores sorting to reject low quality cores. All incoming cores are disassembled and every activity needed during disassembly process is recorded on a computer system as explained by the interviewee:

'We look at it [cores] *from two points of view. From a financial point of view, so everything that we are using to remanufacture that component is recorded on a computer system if the job goes along and once it gets above a certain point it flashes up on the screen and tells them that the job is no longer viable, stop and see your supervisor'.*

Since the company accepts cores in any condition, the remanufacturing process has to be discontinued for some cores. When this decision is made, the company has spent a lot of money for cores processing. The decision to discontinue is mainly due to high need for new components or more additional works that cause remanufacturing becomes too costly and is no longer feasible economically.

There is a document that accompanies each core, but information on the document is not integrated into a wider (OC5) product information database. To identify what new parts that are needed for a transmission and how much cost has been spent to remanufacture the transmission, below is an explanation from the manager.

'We need that document to get parts from upstairs. If we don't have that job number, see that number there, if we don't have that number on that we won't get issued with parts upstairs because the parts guy doesn't know what to put them against, where the costs go. So by the end of that transmission, when we get that transmission to there and it comes out of there, you'll know how much that transmission cost us to rebuild'.

This information is stored in a product information system to help the company remanufacture if the gearbox is returned to them. The information can be used to identify which parts that are damaged and need to be replaced. From the database, there is a lot of information useful for remanufacturing as explained below:

'We need to obviously keep records of everything we do. So we know if we see this transmission again in three or four years time and we see our number we can go back and look at that four or five years ago and we'd know exactly all the components we fitted to that transmission and we'd even know who did it, we'd even know the guy who built it, the guy who tested it and when we sold it'.

6.1.2. Process choices (PC)

The company predominantly adopts (PC1) made-to-order but not all the time. The orders come in small numbers from individual customers that have specific needs. Adding to the complexity is that there is uncertainty regarding the time of orders arrival. Given these order characteristics, there is a high fluctuation of orders and this consequently causes plenty idle capacity. On some occasions, the company has to cope with idle capacity with remanufacturing available stock of cores to build stock of remanufactured products.

Another emerging issue because of the customised orders in small units from customers is uncertain delivery time. Below is a description of how uncertain delivery times are caused by customers that need customised services:

'If a customer asks how long a car will take, roughly, it depends. If nothing goes wrong with any parts or anything like that, it's normally between three and five days. If I've got the transmission in stock, we'll get it back the next day'.

(PC2) Volume of cores supplies from customers is relatively low. The supplies arrive at the facility in units rather than in batches or in bulk. When he was asked about the volume of cores supplies, the interviewee stated:

'It varies. From week to week, every week is different. Every day is different, nothing is the same'.

Due to the customised orders in small volumes, the company charges premium prices to customers. Even the agreements with the OEMs and relationships with franchised garages do not help much to increase the supply of cores. When the interviewee was asked whether these parties supply cores in large numbers, he responded:

'No, not the franchised garages. They will just send you a car when they've got a problem with a car. It's only companies like Hyundai and Chevrolet and places like that

that will send you some transmissions to do a few of them or you maybe get two or three a week'.

In Company A, there is not any specific procedure, manual guidance and customised tools for disassembly. The disassembly is carried out in a straightforward way using (PC3) general tools that can be obtained from general market. When the interviewee was asked whether there is any research in the company to increase the efficiency of disassembly, he responded:

'Not in disassembly no. You just get your gun, take all the bolts out, separate the casings, and pull all the components out'.

It seems that the disassembly process is carried out in an informal way; there is not any specific instruction for it. The employees are given flexibility to carry out any disassembly technique as long as the components are separated.

Company A assigns employees with (PC4) multi-skills rather than specific ones. The managing director explained that it is difficult to equip employees with a range of skills since it takes a longer time and is a slow learning process. On the other hand, he also admitted that specialised employees could do specific jobs faster with a lower rate of mistakes. However, given the company's size, the managing director has made a different policy to adopt multi-skilled employees as opposed to those with specialised skills. He described a cut off value in which multi-skilled or specific skills are suitable for the company as follows:

'The only problem is you're dealing with at my size, I'm at a point where people are almost at the top end of having multi-skilled. Anything below 25 is definitely multi-skilled. But with 25, 50 employees it's much more efficient to use people doing the same job all the time'.

6.1.3. Product attributes (PA)

Since the company receives cores from individual customers from the market, there are a lot of product variances in terms of pattern of use, length of use, year of production brands etc. These differences cause many variances in the potential (PA1) value of recovered products. In addition to this, the company does not organise sorting so that the company disassembles the cores regardless of the condition. The absence of cores sorting increases the uncertainty of the potential value of recovered products and time to disassemble. A longer disassembly time is typically needed for cores that are sticky, too dirty or rusty. This problem is usually found in gearboxes for old model cars that are no longer produced by the OEMs. In this circumstance, the employee who carries out disassembly has to maximise the recovery of the components. This is because the new components are no longer available in market and if they are, the price would be extremely high.

Gearboxes tend to be (PA2) functional products rather than innovative products. The stock of gearboxes could stay in the company for up to two or three years. As a matter of fact, there are gearbox stocks produced in the year 2000 although the number is not as many as more recent models. The focus of the company is how to forecast which models that are still wanted by the market considering the limited capacity of the warehouse.

The company does not carry out any research or similar activities to identify the most efficient (PA3) sequence of disassembly. All disassembly activities are carried out based on experience of disassembling the same or similar products in the past. Sometimes, the company accepts new type of gearboxes in that they have never seen before. In such cases, disassembly takes a longer time and needs more resources.

With regards to the (PA4) level of disassembly, all the components are dismantled until all the components are separated and there is nothing left on the casing. In other words, the gearboxes are disassembled completely. This decision is applied to all gearboxes regardless of the condition, model and production year.

(PA5) Type of materials for gearboxes is quite homogenous. Gearboxes are predominantly made from steel iron, aluminium, brass etc. More recent models are lighter than in the past. The components made from softer materials such as gaskets, seals, bearing or friction plates could be disassembled destructively because they have to be replaced. Due to the destructive disassembly method being applied, disassembly can be done more quickly.

(PA6) Number of components within a gearbox can vary between 150-200 depending on the model, manufacturer, year of production and number of speeds. For example, the average number of components for a 5-speed transmission would be roughly 180. This figure would increase slightly if parts such as rings, nuts and bolts are added.

In general, there is an indication that more recent gearbox models are easier to disassemble in comparison to the old ones. It seems that OEMs have adopted (PA7) ecodesign principles in gearboxes from time to time. Nevertheless, the adoption does not always give advantages to remanufacturers. In some circumstances, the use of ecodesign principles even hinder remanufacturing. For example, the use of less material is one of the techniques to reduce waste at the end of the product life. This technique could cause a reverse effect on remanufacturing. Here is one of the example statements from the interviewee:

'...20, 30 years ago a drum would have had a wall thickness of maybe eight, nine, ten millimetres, something like that. You'll never get a wall thickness now any more than 3 millimetres and so it ***doesn't leave much scope to re-machine it****'.*

In short, there is not any clear evidence that the gearboxes have been designed with eco design principles to make disassembly easier.

There is not any technology attached to gearboxes that can help disassembly. (PA8) Smart technologies such as active disassembly or other similar technologies that could help disassembly were not found. Rather, physical disassembly process is carried out without any assistance of technology embedded in the product.

6.1.4. Analysis with existing studies

In this section, empirical findings that have been presented in narrative discussion above will be analysed with existing studies. The purpose of the analysis is to examine whether evidences confirm, unconfirmed or extend existing studies.

Table 6.1. Analysis of findings in Company A with existing studies

No.	(CODE) Factors	Result of analysis	Key findings from this case and relevant literature
Organisational characteristics			
1.	(OC1) Degree of the relationship with OEMs	Confirm and extend	Company A obtains most of its cores come from individual customers in the market. For this reason, Company A disassembles most of incoming cores. This confirms the literature explaining that independent remanufacturers' priority is to save the parts (Sherwood et al. 2000) since they have more difficult problems regarding cores supplies compared to contracts and OEMs remanufacturers (Saavedra et al. 2013; Lind et al. 2014).
2.	(OC2) Knowledge transfer from OEMs	Confirm	The interviewee admitted that any support from OEMs could have been useful. Unfortunately, there is not any OEMs who interested to support the company. If there were some support, there would be significant cost reductions (Westkamper 2003).
3.	(OC3) Size of the remanufacturer	Confirm	As a small and independent remanufacturer, Company A does not invest much of its resources in the disassembly technology. Disassembly technology that requires high cost investment is not found in the company. This evidence confirms existing literature explaining that bigger remanufacturers typically have more automated processes for disassembly in comparison with the smaller size ones remanufacturers (Williams et al. 2001).
4.	OC4 Cores sorting	Confirm	The company does not attempt to reduce the variability of cores condition using cores sorting although the manager admitted that without cores sorting there are unnecessary costs incurred. These findings confirm literature in the sense that without cores sorting the process of remanufacturing would be more expensive due to cores quality variability (Tagaras & Zikopoulos 2008; Zikopoulos & Tagaras 2008).
5.	(OC5) Product information database	Confirm	In general, the findings support the literature in the sense that the product information database is useful for remanufacturing (Chung & Wee 2010). This evidence was found in Company A in which information is used for estimating the order of new parts and estimating costs to remanufacture.
Process choice			
6.	(PC1) Make-to-order versus make-to-stock	Confirm	Company A predominantly adopts made-to-order in which disassembly starts once the number of orders from customers has been received. This commonly happens in independent remanufacturers which are typically SMEs. This finding is consistent with the study of Ferrer and Whybark (2001) who stated that smaller remanufacturers typically adopt MTO competing in uncertain and complex environments.
7.	(PC2) Volume of cores supply	Confirm	The volume of cores supply in Company A is relatively low. High variety of the product model adds to the complexity. For this reason, disassembly cannot be carried out in an efficient way (Jaber & El Saadany 2011; Reveliotis 2007), and consequently, the company gains sufficient incentive by charging customers above normal price. In this case, high price charged to customers ensures that the remanufacturers receive sufficient incentive (Wu 2012).

8.	(PC3) Specific versus general tools and equipment	Confirm	The use of general tools makes disassembly time longer but it allows more flexibility (Sundin et al. 2012). This is a typical method adopted by remanufacturing companies (Ferrer & Whybark 2001). Given the small size of the company, it lacks investment in technology for disassembly. Rather, the company adopts existing tools readily available in the market to carry out disassembly.
9.	(PC4) Generic versus specialised skills	Confirm	The present finding supports the work of Guide et al. (2005) which stated that the workers tend to use general tools as opposed to specific ones. The employees even use the same place to disassemble different models of gearboxes, put all disassembled components in the same place, and sometimes carry out inspections and cleaning at the place where disassembly has been carried out. Employees in Company A are multi-skilled and easily transferred between different positions, and given flexibility to carry out tasks. These findings are consistent with the work of Westkamper et al. (1999) explaining that employees should be given more responsibility and job enrichment. They further give an example how assign employees for both assembly and disassembly tasks.
Product attributes			
10.	(PA1) Value of recovered products	Confirm and extend	Value of recovered products varied widely from one another. Old cores that were produced 40-50 years ago have extremely high value because of their scarcity. These cores are categorized as classic products so that their value becomes extremely high for aesthetic reasons. These cores are more difficult to disassemble due to a lack of product information, previous experience and aged cores. These findings support the studies which stated that high value components are important to recover (Ferrer 2001; Westkamper et al. 1999; Subramoniam et al. 2009). This case study also extends existing concepts which claim that high value cores are typically obtained from latest product models. Meanwhile, this case found that components from old cores are highly valuable because they are not produced by the OEMs anymore.
11.	(PA2) Functional versus innovative products	Confirm	Gearboxes are functional products whose designs do not change dramatically in a short time so that it helps Company A to organise disassembly more easily. The company can keep the cores for several years without worrying the cores value being depreciated significantly. Consequently, disassembling gearbox does not entail frequent changes of tools and equipment. If the products are susceptible to fast technological change, it is not interesting from economic perspective to carry out remanufacture (Chiodo & Ijomah 2012; Ijomah et al. 2007a).

12.	(PA3) Sequence of disassembly	Confirm	Sequence of disassembly has not been determined precisely or standardised formally. Employees who undertake disassembly are given room to be flexible so that there is high time variation between disassembling one product and another. The interviewee admitted that this is not the most efficient way. These findings are consistent with previous studies which demonstrated that there is some specific disassembly sequence that could reduce cost, minimise time and require less effort (Smith et al. 2012; Lambert 2002) but the company does not adopt this strategy.
13.	(PA4) Level of disassembly	Confirm	The manager admitted that undertaking full disassembly is not always economically beneficial. This finding confirms existing studies that demonstrate that full disassembly is not always economically efficient (Smith & Chen 2011; Lambert 2002).
14.	(PA5) Types of materials	Confirm	Gearboxes predominantly consist of metal-based materials. This evidence confirms existing work which found that as much as 75-80% of materials of vehicles are made from metal (Gerrard & Kandlikar 2007). Homogeneity of materials makes disassembly easier because there is not any hazardous, sensitive or poisonous material requiring specific treatment during disassembly.
15.	(PA6) Number of component	Confirm	There are roughly 150-200 components within a gearbox depending on the models. Models that have a higher number of components require more effort to disassemble because a higher number of components means a higher number of joints. This fact is in accordance with the argument by Westkamper et al. (1999) which stated that 50% of disassembly tasks are disconnecting joints which consumes more than 50% of the total disassembly time.
16.	(PA7) Ecodesign principles	Unconfirm	Gearboxes are easier to disassemble than they used to be. However, the respondent is not convinced if the OEMs deliberately using less materials in order to make the products more environmentally friendly. The use of less material even hinders remanufacturing. It makes the gearboxes lighter and thinner so that does not give much room for reprocessing. One of the explanation of this finding is that OEMs might use product design to reduce the opportunity of products from being remanufactured (Wu 2013; Sundin et al. 2012).
17.	(PA8) The use of smart technologies	Unconfirm	This study found different results from existing works. Previous works suggested that the use of smart technologies such as sensor embedded technology (Ilgin & Gupta 2011), active disassembly (Ijomah & Chiodo 2010) or intelligent device (Yang et al. 2009) can assist disassembly; however this study does not find that result. There is not any specific disassembly technology that is used in gearboxes to assist disassembly.

6.1.5. Some highlights of the findings

Following the suggestion of Maxwell (2013), rich qualitative data that has been presented above should be summarised to highlight the major themes found in the case. The following points are the summary of strategies adopted by Company A to manage its disassembly resources so as the disassembly can run smoothly. To achieve this purpose, Company A:

- ***Gives higher priority to maximise part recovery rather than streamline the material flows in disassembly.*** As an independent remanufacturer, Company A purchase stock of cores and has to make a return on the purchase. A core which is scrapped by contract and OEM remanufacturers might be processed by an independent remanufacturer like Company A although it takes a long time to remanufacture.
- ***Uses any available equipment to move and handle the disassembled components.*** There is not any specific equipment devoted to moving and handling the disassembled components; and if available, the equipment is also used for other purposes.
- ***Carries out full disassembly and the sequence has not been determined in advance.*** There is not any formal document that provides guidance on how to disassemble. The employees disassemble the cores based on their preference and experience. Due to this unformalised procedure, there is a big variation between cores in terms of disassembly time and cost.
- ***Organises job rotation frequently since there is not any job specialisation***. This is because the employees have multi skills and the task to disassembly does not need specific formal requirements. There is no regulatory body that requires employees to have certain qualification to conduct disassembly.
- ***Uses informal training through peer-by-peer coaching.*** The training is informal in nature and not structured. More experienced employees provide the training to less experience employees during daily operations.
- ***Uses multi-purpose equipment available in the market.*** All cores regardless of the type, models, or year of production are disassembled at the same facility. This strategy allows resource sharing between different product models and reduces fixed cost investment.
- ***Spends low fixed cost facility and uses multi-purpose equipment.*** All cores are disassembled at the same facility cores regardless of the type, models, or year of production. The facility is used to disassemble cores with different models, manufacturers and year of production.
- ***Runs production in low volumes and serves niche market.*** Most of the orders are in small volumes because the orders come from retail customers who demand customised services. For these customers, the company charges premium prices. On many occasions, the company does not receive any orders from customers so that the company processes the cores from the stock to reduce idle capacity.
- ***Builds a considerable high amount of stocks cores and remanufactured products.*** The stocks are used to reduce idle capacity in case there are not any orders from customers. Periodically, the stocks are dumped or sold to other parties at considerably low prices once they reach a certain level.
- ***Adopts a flexible production schedule.*** This is due to uncertain orders from retail customers in the market. Employees who carry out disassembly are multi-skilled workers that can be rotated with other positions.
- ***Does not organise sorting and most of incoming cores are accepted.*** The company accepts cores in any condition because the employees are flexible to disassemble any product models with a large variety of quality condition. The company tolerates problems during disassembly such as longer time to disassemble and high resources spending to disassemble caused by the variance in cores condition.
- ***Decides to disassemble all cores completely without a depth analysis.*** When disassembly is underway, sometimes the company just realises that it is too costly so the disassembly is discontinued.

6.2. Company B

Company B is a contract remanufacturer based in Bristol that has operated since 1978. The customers are automotive manufacturing companies including FCSD, General Motors, Volvo, Mitsubishi Motors, Jaguar and Land Rover. The company employs 75 staffs with different skill sets and expertise levels in order to produce about 15,000 remanufactured products which resulted in 7 million pound turnover in 2012. Considering the amount of turnover and number of employees, Company B is categorised as a medium-sized enterprise according to the Department for Business Innovation & Skills (2014).

The business of the company is predominantly gearbox remanufacturing which accounts for 75% of the company's operation. The company receives cores from OEMs who agree to sign contractual agreement. The cores from OEMs are stored in a 30,000 square metre warehouse facility, which can holds stocks up to 20,000 cores at any one time; this figure is equivalent to more than one year production. Given that company B remanufacture cores that are readily available in the warehouse, the remanufactured products that are dispatched to customers are not the same as the cores that were just received from them.

6.2.1. Organisational characteristics

The company has built considerable well managed (OC1) relationships with OEMs. The cores arrive at the company's facility almost every day, which indicates the company has consistent supplies of cores from the suppliers.

Once the cores arrive at the warehouse, the cores ownership is still held by the customers, and Company B charges them for storing the cores in the warehouse. Accordingly, the company does not bear the holding cost resulting from a considerably high number of stocks.

Being a contract remanufacturer brings about consequences such as the need that remanufactured products have to comply with the requirements of the OEMs. To achieve this purpose, the company receives (OC2) knowledge transfers from the OEMs. A director gave an example of how the transfer occurs:

'We worked with their engineers when design our processes and facility. They have their own performance specifications of the products, so we make our processes comply with those performance requirements'.

However, specific knowledge transfer for disassembly does not happen since the OEMs do not carry out disassembly. Therefore, the OEMs could only transfer general knowledge that might be relevant for disassembly. This includes transfer regarding how the expected standard of the remanufactured products are. The company then used the standard as guidance so as the disassembly facility could produce outputs that meet the specification.

(OC3) Size of the remanufacturers influences on the preference of the OEMs to work with. OEMs prefer to sign contracts with companies who have better readiness to adopt their standards whilst bigger companies have a better chance to be candidates. Although the contracts obtained from OEMs contribute to the expansion of the contract remanfuacturers, initial qualification is still needed. In addition, the bigger sized remanufacturers have better standard in the remanufacturing operations. An example of advantage obtained by Company B due to its company size is that it has obtained TS 16949:2002 certification.

(OC4) Cores sorting happened at several phases. First, when the cores arrived at dealers' facility, second, when the cores are received by the OEMs and lastly, when the cores are at the company's warehouse just before the cores are moved to disassembly facility. The second phase is carried out because the OEMs have their own standard that could be tighter than those of the dealers'. In the last phase of sorting, the cores are classified because they have been in the facility for some time resulting in deterioration or obsolescence to some extent. With such a method, unnecessary cost because of disassembling low quality cores can be avoided.

Despite the company having a (OC5) product information database, it seems that the system is utilised to support remanufacturing but not for disassembly in particular. Every remanufactured product is attached with a numbered label and entered into database. The use of the label is not to manage uncertainties during disassembly if the products come back to company again. Rather, it is used managing quality during remanufacturing process. When the director was asked regarding the benefit of the label to support disassembly, he responded:

'It does not really matter to us; as long as the cores come in, we remanufacture it'.

On the other hand, he explained how part identification supported with product database can be used to manage quality of remanufactured products as follows:

'….if anybody needs to know we can tell them exactly what parts went into the products, who did it, when they did it and when we performed our test'.

6.2.2. Process choices

Company B organises (PC1) made-to-order production systems based on orders from the customers – i.e. the OEMs. Although the company holds a considerably high number of cores, the company attempts to minimise stock of finished products by dispatching finished products to customers as soon as the remanufacturing process has been completed.

Company B gains benefit from possessing high (PC2) volume of cores supply. As mentioned previously, there are about 20,000 core stocks at any one time. This high volume of cores is sufficient for the company to adopt some sort of production line for its remanufacturing operations. To support the line, disassembly should be carried out in a quick and efficient manner in order to avoid it is being the bottleneck. Even though the company remanufactures different product models, this can be offset by the high volume of the cores so as it can reduce fixed cost.

Despite adopting the made-to-order production system, disassembly facility in the company was not supported with flexible (PC3) tools and equipments. The company adopt customised tools and equipment to enable quick and efficient disassembly for supporting disassembly line. There is a research and development (R&D) team who design customised tools and equipment, set-up facility and find the best way to carry out remanufacture. The respondent pointed out the amount of resource needed to establish the facility as follow:

'One of these work stations may cost 3,000 pounds to assemble. But that 3,000 pounds will be spread over maybe 5 years production. So fixed cost goes right down but the labour is always there all the time exactly the same'.

In addition to this, the operators of tools and equipment have to attend in-house trainings to acquire specific (PC4) skills and knowledge. The company organises formal trainings for its employees coupled with evaluation to assess whether candidates have meet qualifications to carry out disassembly. A R&D team designs the materials for the training and evaluation. Regarding the training, the director illustrates the program like this:

'We use training system called as 3-1-3 so there are every person can do 3 jobs minimum, and every job can be done by 3 people at least'.

With this training program, the employees have specialised skills with flexibility to some extent. In this manner, there is still possibility that the employees are rotated to different positions in order to improve capacity utilisation.

6.2.3. Product attributes

The potential (PA1) value of recovered products is high and offers economic benefit. To gain more benefit, the company ensures that there are high number of core supplies and organises its disassembly in high volume batches. These methods can reduce two types of fixed costs. First, fixed cost to build the facility; and second, the fixed cost to set up the facility just before the disassembly starts.

Gearboxes tend to be (PA2) functional products rather than innovative products. The products have a considerable long life, relatively stable technology and emphasis on functionality rather than innovation. In this instance, the company gains some benefit as not only do they gain because of the relatively stable residual value, but also from opportunity to build long contract periods with OEMs, and utilise the same facility for long period. Regarding the long life, functionality and stability of the technology, the interviewee states:

'But, transmission can come back to us many times. So, we have a transmission that comes to us now but we worked on it 15 years ago'.

Company B can identify that the gearboxes come back to the company again because there is a traceability number on the products that it releases.

Although employees can disassemble gearboxes using some different sequences, the (PA3) sequence of disassembly has been determined in advance through formalised and documented procedures developed by a R&D team. Using these procedures, combined with the skills obtained from training and supported with customised tools and equipment, the employees can disassemble gearboxes very quickly. Regarding the strict disassembly sequence in Company B, the interviewee described:

'It can really only be done in one sequence because you have to take the parts off and get the gears then you have to get the back gears up to the front gears. So, yes it is very specific sequence...'.

In terms of (PA4) level of disassembly, all gearboxes are disassembled completely. This is due to the need to examine every component within the gearbox before further processes. Also, carrying out full disassembly for gearboxes is not expensive because the products do not have complex product structure.

Theoretically, a wide (PA5) variety of materials cause complexity of treatment during disassembly. For example, the need to keep the components in a room with certain temperature, wear cloves due to unstable materials or use protection because of toxic materials. However, this phenomenon is not found in Company B as most gearboxes are created from steel based materials such as iron, aluminium, brass, and sometimes magnesium. Certain components, particularly those made of magnesium need more careful treatment because of their high cost. In addition, the material catches fire more easily than others such as aluminium or steel. Given that most of the components are made from relatively homogenous materials, all the components are treated in the same way, e.g. put in the same crate, transported at the same time, etc. This homogeneity makes disassembly easier particularly during moving and handling the components in post-physical disassembly process.

The interviewee admits that (PA6) number of components is one of factors affecting disassembly time and cost. Other factors that might affect them are the structure of the products, joints and type of materials. A good understanding of these factors will help companies to reduce disassembly cost and time.

There are evidences that very few products have adopted (PA7) ecodesign principles and this causes disassembly to become costly. Many products are constructed to allow robot assembly without considering how to disassemble them once they have reached the end of their life. The interviewee acknowledged the situation as follow:

'We see very few products which are designed for disassembly. They are all designed for robot assembly, which make product building very easy. Then, when we have to pull the parts, we have to get totally separate circle of metal, a big washer, welded on to the bearings. So we've got to get somebody to hold on to pull off so that cost another 1.50 pound per transmission…You know with 12, 15, 19 thousands [volume of production] *a year, it becomes expensive'.*

(PA8) The use of smart technologies was not found in this case study. It seems that the company does not aware of smart technology like active disassembly technologies could be useful to make disassembly easier. The company preferred to focus on how to carry out disassembly with existing techniques.

6.2.4. Analysis with existing studies

Table 6.2 aims to highlight the key findings to answer the first research question from the narrative description above. Given the first research question is deductive in nature, the relevant literature related to the findings is also presented to connect with existing findings.

Table 6.2. Analysis of findings in Company B with existing studies

No.	(CODE) Factors	Result of analysis	Key findings from this case and relevant literature
Organisational characteristics			
1.	(OC1) Degree of the relationship with OEMs	Confirm	As a contract remanufacturer, Company B signs contractual agreements with OEMs to reduce the uncertainty supply of cores. This finding confirms an existing study explaining that developing agreement with cores suppliers could reduce uncertainty of cores supplies (Lind et al. 2014) and OEMs could be a good alternative as cores suppliers (Saavedra et al. 2013; Ijomah 2009).
2.	(OC2) Knowledge transfer from OEMs	Confirm	Company B works together with OEMs - as its customers - to develop standards of expected output of the products. Product knowledge from OEMs are transferred to the company as suggested by Saavedra et al. (2013). Support from OEMs could be useful to reduce costly operations particularly when the process require specific tools and equipment (Westkamper 2003).
3.	(OC3) Size of the remanufacturer	Confirm	The findings support the idea of Williams et al. (2001) who explained that small and big sized remanufacturers adopt different strategies. Company B employed different operators for different stages of remanufacturing and assigned certain employees with specific skills. These strategies are different from those in small sized remanufacturers in which an employee remanufactures a product from start to finish.
4.	(OC4) Cores sorting	Confirm	These results were consistent with those of other studies which suggested that cores sorting are useful to reject low quality cores and avoid unnecessary disassembly (Zikopoulos & Tagaras 2008; Loomba & Nakashima 2012; Galbreth & Blackburn 2006; Sundin & Bras 2005). Accordingly, unnecessary cost from disassembling low quality cores can be avoided. In addition, disruption that might be caused by spending extra time for disassembling low quality cores also can also be avoided.
5.	(OC5) Use of product information database	Unconfirm	Existing study found that the use of product information database offer benefits (Veerakamolmal & Gupta 2002). The database can help remanufacturers to identify parts need for replacement so as procurements staff can order components for replacement earlier (Ferrer 2003). However, the product information database in the company is not used to support disassembly. The database is used to manage the remanufacturing quality and track down what have been done to the cores.
Process choice			
6.	(PC1) Make-to-order versus made-to-stock	Confirm	Company B adopts MTO for its disassembly process and does not hold stocks of disassembled components. The present findings seem to be consistent with other research which found that disassembly always starts after customer demand has been received (Tang et al. 2007).

7.	(PC2) Volume of cores supply	Confirm	Company B organises high disassembly capacity because there is high volume of cores supplies. Thus, the company can gain economic benefit due to high volume of cores supply. This corresponds with earlier observations that showed high capacity gains economic advantage from the design of specialised tools and equipment (Desai & Mital 2003), and supports employee learning (Jaber & El Saadany 2011) so that disassembly can be carried out more efficiently (Reveliotis 2007).
8.	(PC3) Specific versus general tools and equipment	Confirm	The company adopts customised tools and equipment for disassembly which are developed in-house. These tools and equipment are used to support some sort of production line so that disassembly can be carried out efficiently and quickly. These evidences support the literature which suggest that specialised tools and equipment can disassemble more efficiently but it is less flexible (Franke et al. 2006; Sundin et al. 2012). This is because they need set up time and complicates the employee scheduling (Seitz & Peattie 2004).
9.	(PC4) Generic versus specialised skills	Confirm	The employees in Company B are required to attend training to gain skills in order to be capable of performing disassembly tasks efficiently. This finding supports the work of Ferrer (2003) who found that the replacement of unskilled employees with skilled ones results in significantly higher reclaimed residual value.
Product attributes			
10.	(PA1) Value of recovered products	Confirm	Company C organises sorting to ensure that only cores with sufficient potential yields that will be recovered. These findings further support the idea of previous studies which suggest that disassembly is a complex process because the yield from disassembly is uncertain and increased product value affect positively decision to remanufacture (Ferrer & Whybark 2001; Ilgin et al. 2011; Ferrer 2003). The quality of incoming parts quality might affects the potential residual value and the optimum disassembly planning that have been prepared in advance (Sutherland et al. 2002).
11.	(PA2) Functional versus innovative products	Confirm	The disassembly facility for each product in the Company B can be used for up to 5 years. This indicates that the design of the products is relatively steady- a typical characteristic of functional products. This supports Franke et al. (2006) who stated that the critical factor affecting tools and equipment changes is the introduction of new products. Introduction of new products leads to change in tooling and equipment and therefore, remanufacturers require more investment for new tooling and equipment. A similar view is expressed by Ijomah et al. (2007a).
12.	(PA3) Sequence of disassembly	Confirm	The employees who disassemble the gearboxes have been trained and provided with manual guidance to do their jobs. Accordingly, the employees follow a strict sequence to disassemble in an efficient way. These findings corroborate studies which demonstrated that there is an optimum disassembly sequence that can be followed to increase profitability (Shimizu et al. 2010; Kang & Hong 2012; Smith et al. 2012).

13.	(PA4) Level of disassembly	Confirm	Although some literature claim that full disassembly is not always economically efficient, this case study found that Company B carried out full disassembly (Smith & Chen 2011; Lambert 2002). One of the explanations could be that the potential value of recovered components outweighs the cost of disassembly. This finding is in line with literature which explains that decision regarding disassembly level should consider the potential value of recovered materials and the cost to disassembly (Ryan et al. 2011).
14.	(PA5) Types of materials	Confirm	Gearboxes mostly consist of iron, steel, aluminium and some magnesium. Only a small portion of materials made of magnesium need more careful treatment because it is easy to catch on fire. These findings support the study of (Gerrard & Kandlikar 2007) who found that as much as 75-80% of vehicles materials consist of metal. In addition the evidences are consistent with a study conducted by Feldmann et al. (1999) who find that components made of homogenous material require identical treatment during disassembly process.
15.	(PA6) Number of component	Confirm	One of managers in Company B admited that number of component affects disassembly. This is consistent with existing literature which find that products with higher number of components need longer disassembly time (Zwolinski & Brissaud 2008) and require more resources to disassemble (Veerakamolmal & Gupta 2002). Company B overcomes these problems using specialised tools and equipment operated by highly skilled employees.
16.	(PA7) Ecodesign principles	Unconfirm	The adoption of ecodesign is not confirmed in this study. This case study shows lack of evidence that the gearboxes have been designed with ecodesign principles. This causes some difficulties not only during disassembly but also during remanufacturing in general. This finding confirm existing study showing that product design is the cause of parts rejection due to failure to recover during disassembly (Williams et al. 2001). Products that are designed for disassembly are more easily maintained, repaired, and cannibalised when there are too many damaged parts (Ferrer 2001).
17.	(PA8) The use of smart technologies	Unconfirm	In contrast to existing literature that suggest the use of smart technologies to assist disassembly (Chiodo & Ijomah 2012; Ijomah & Chiodo 2010), no evidence of the technologies adoption was identified. One of reasons could be that smart technology like active disassembly is still in its early stages of development, so that not every product is ready to adopt the technology.

6.2.5. Some highlights of the findings

The following are the summaries of the qualitative data which are organised into major themes following suggestion of Maxwell (2005). The following points are the summary of strategies adopted by Company B to manage its disassembly resources so as the disassembly can run smoothly. To achieve this purpose, the company:

- ***Stabilises the volume of production over time.*** The company attempts to maintain volume of production at a constant rate. A large number of cores coming from diversified customers ascertain that the company never lacks demand and supply of cores.
- ***Uses customised design equipment to move and carry disassembled components.*** Different gearbox models use different crates to carry the components during the post-physical disassembly activities. The crates are designed specifically for different product models. All of this equipment is intended to minimise the risk of damaged components and streamline the component flows.
- ***Develops strict procedures to disassemble.*** Employees disassemblecores and then put disassembled parts into the customised designed crates in a very short time, because they are supported by a manual guidance. All these steps have been prepared by a research team. The employees are familiar with where each piece of the component should be placed in the crate.
- ***Equip employees with specialised skills.*** The employees are organised using 3-1-3 schemes to allow job specialisation. In this scheme, there is an employee skill matrix that can map who can do what. Employees can do 3 jobs, in which they have the expertises, but not all jobs.
- ***Trains the employees to gain product knowledge and to use the specialised tools and equipment.*** Employees do not necessarily have formal qualification but they have to attend an in-house training developed by R&D team.
- ***Designs the factory much like a production line that uses specific tools to disassemble and customised equipment for handling disassembled parts.*** The cores flow in the line from one shop floor to another. Once the cores have been disassembled and the components have been put in the customised crates, they are moved to other shop floors using this line.
- ***Spends high investment to set up customised physical infrastructure such as tools, equipment and disassembly shop floor.*** Tools and equipment that are used to disassemble require customised designs for different gearboxes types. For example, the company spends approximately as much as 3,000 pounds for each type of gearbox. This cost is spread over 5 years.
- ***Uses high volume lot sizes***. This is because the company adopts some sort of line production system to serve orders from industrial customers (OEMs). Production in high volume lot sizes is preferred rather than in units to reduce fixed cost.
- ***Stocks a large number of cores. The cores arrive to the facility daily from different customers so that the company never lack of cores supplies.*** There is no stock of remanufactured products because they are always dispatched to the customers once the remanufacturing has been completed.
- ***Adopts a robust production schedule.*** This is intended to streamline the flow so that the disassembly runs smoothly and efficiently. To make disassembly runs quicker, typical problems in gearboxes have been identified. Accordingly, some components that cause problems and cannot be used again are disassembled destructively.
- ***Conducts cores sorting***. This is intended to reject low quality cores to enter the disassembly shop floor. After the cores have been sorted, the cores quality becomes more homogenous. Low quality cores can cause some disruption and disassembly time longer than normal, whereas quick disassembly is the main purpose that the company attempts to achieve.
- ***Disassemble completely all cores that have been sorted.*** Cores that have been sorted are disassembled completely in a fast and efficient way. Disassembly can be carried out efficiently because the cores are relatively homogenous after they have been sorted.

6.3.Company C

The company is part of a global holding company that covers a wide range of businesses and operations and has operated remanufacturing services since 1973. Company C, located in Rushden, Cambridgeshire, is one out of two branches remanufacturing services in the UK. The other one is based in Shrewsbury, which is also the head office for the Europe. The branch in Rushden that employs 103 skilled and semi-skilled workers used to be under the name of Wealdstone Engineering which was then acquired by the Company C's holding company as part of its expansion to offer remanufacturing services in the UK.

In terms of the type of remanufacturers, the company can be classified into three types of remanufacturers: an OEM remanufacturer that remanufactures its own engines and equipments, a contract remanufacturer that offer third-party services to automotive OEMs, and an independent remanufacturer that remanufacture some components. In this study, the unit of analysis from this company is automotive engines and considers Company C as a contract remanufacturer. This is due to the fact that the volume of automotive engines remanufactured in this company is much higher compared to other product types with production volume of 4,172 remanufactured engines and 38,564 components in 2010. Overall, during the year the company generated turnover as much as 17.83 million pound sterling. The company serves 26 automotive OEMs including Aston Martin, Mercedes Bens, Audi, Ford, and Land Rover, to name a few.

6.3.1. Organisational characteristics

Cooperation with the OEMs is essential in order to reduce the uncertainties in acquiring cores. The contract varies from 3-11 years and is subject to agreement with the customers. As a contract remanufacturer, Company C buys cores mainly from the customers, which are OEMs, and then they are sold back to the customers after they have been remanufactured. In addition to this, the company also obtains some cores from dealers. Under such circumstance, the company does not have much problem to obtain cores. In sum, (OC1) degree of the relationship with the OEMs has a positive influence toward availability of cores.

As mentioned above, Company C signs contracts with a number of OEMs. Under the contracts, the company obtains (OC2) knowledge transfer from the OEMs regarding know-how to undertake remanufacturing, except for some brands, namely Land Rover and BMW. The supports include how to set up the facility, how to train employees and how to set up testing standard for the final products, etc. The OEMs have interest on providing the support since these ascertains that the final remanufactured products have the same standard as the new-ones. Despite contractual agreements that have been signed with the OEMs, obtaining information and awareness from the OEMs is not always easy. A respondent described:

'Particularly OEMs give their information very, very carefully, and they very, very worried about who knows how the system works, and who knows how they get back. You can get information if you wanted, but it is normally tortuous, but you can get it'.

(OC3) Size of the remanufacturer does matter for remanufacturers to build partnership with the OEMs. OEMs seem to hesitate investing their resources and developing relationships with small companies. This is the reason why most independent remanufacturers are predominantly SMEs. From the perspective of the remanufacturers, the bigger the size of the company, the easier it is to develop standardisation in remanufacturing process. Given that the size of Company C is big, there are a lot more standardised operations than those in the smaller ones. In short, the bigger the size of the company, the easier it is to standardise the disassembly. One of the managers expresses the situation like this:

'I mean certainly somewhere likes our company, our company live on standard processes, I mean, like it or not, there will be requirements. I suspect with a smaller remanufacturer, there's probably not, you probably find it's a bloke who has always done it that way, because that's the way it works'.

Before the cores are disassembled, there are two levels of (OC4) cores sorting. The first is when the engines are taken from the vehicles, which happens at the dealer's facility before the cores are taken back by the OEMs. The second is at the company's facility just before the cores are disassembled into components and classified into component families. At this stage, the sorting is conducted at a more detailed level in order to examine the condition of components before they are disassembled. To some extent, it is possible to identify components whose conditions are not feasible to recover. The way sorting is useful for the remanufacturer is described by an interviewee like this:

'The quality of the information, feedback, and the actions taken from it [cores sorting] *are where the savings are made'.*

Therefore, the company can avoid more costly operations by rejecting cores that are not necessary to be disassembled. Furthermore, one can determine which components are to be recovered and hence, pull out the only desired ones. These components are then cannibalized with components from other cores. In such circumstance, employees undertake selective disassembly and the rest of the components are rejected.

(OC5) Use of a product information database to support disassembly is not found in this company. It seems that the company relies on information gathered from their sorting in its facility just before the cores are disassembled. It could have been more beneficial for Company C if the OEMs or the dealers who carry out previous cores sorting forwarded the databases containing the sorting information to the company. The OEMs and the dealers seem to keep the data and information for themselves, and do not want to share this with other parties. One explanation could be that it contains confidential information regarding product faulty that other parties are not permitted to access. In this case, the information is lost as described by a respondent:

'... it's completely lost [information], *and there's no* [information]. *I've asked more than once, and they've sort of said mmmmm* [shaking head]*'.*

6.3.2. Process choices

In general, Company C predominantly adopts a (PC1) MTO system with a job shop layout and uses separate dedicated areas for different processes. Once the orders have been received, production schedules can be arranged including allocation of resources for disassembly. Tools and equipment for disassembly are located in fixed areas so that the employees need to come over to these locations.

With regard to (PC2) tools and equipment, the company needs a mix between general and specific purposes for disassembly with the former outweighing the latter. A manager gives an example pertaining to the tools and equipment like this:

'…for disassembly it's pretty straight forward. It's really a manual process, most of it [tools and equipment] *can be obtained anywhere, but some are not. So, we custom build trolley's or something like that. So, when parts come after* [the parts] *can go to the wash bath in the right order and keep together that kind of things'.*

(PC3) Volume of cores supply affects the decision of the company to accept or reject the remanufacturing contracts. The company also needs to review regularly the economic feasibility of remanufacturing operations, considering the volume of supply typically goes up and down from time to time during the contracts. This fluctuation affects the feasibility by influencing the cost per unit product. One of the respondents explained the situation like this:

'So this is one of the things I would say, is that it needs to be a dynamic model because the cost when you start and the viability of when you start of remanufacturing, changes through the program because as the volumes go up and down, things that were worth remanufacturing, aren't anymore, or they are when they weren't before so I do think you need something that is dynamic and moves with it'.

Before Company C company signs contracts with its customers, it is important for the company to ensure that the required resources are available including tools, equipment, and employee skills and qualifications. Then, they can translate the requirements from the customers into operations strategies of the remanufacturing. This is due to the fact that most of the works from customers are unique so that managing the voice of the customer is of high importance.

(PC4) Employee skills specialisation in Company C is developed through a series of stages. The skills needed to carry out remanufacture in particular are arranged in a 3-1-3 scheme so that the employees have some degree of specialisation. In this scheme, employees who are assigned to carry out disassembly tasks also possess skills to carry out other jobs. As such, idle capacity can be avoided and therefore more optimum employee allocation is resulted. If the employees are not available, employees from other departments can be allocated to the disassembly shop floor to substitute disassembly shop floor workers. This situation was described by a manager as follow:

'We have a standard which is three-by-one and one-by-three so every person should be capable of at least three jobs, and every job should be done by at least three people. That gives us a plenty of holidays and something like that'.

6.3.3. Product attributes

(PA1) Value of recovered products increases the tendency to disassemble products which eventually will be remanufactured. High expected residual value of the products is the main motive for remanufacturing. Most of these high value components have to undergo non-destructive disassembly to recover and do not allow any damage.

Automotive products remanufactured in Company C have relatively stable value over time. The products in this company can be remanufactured up to 2 or 3 times with the same quality as the new ones. Automotive products are less innovative than others such as electrical, electronic or information technology products. Considering these characteristics, the products tend to be (PA2) functional although to some extent, contain innovative elements.

Most of the engines have certain (PA3) sequences of disassembly that should be followed. Different types of engines have a specific sequence that should be followed by the disassembly workers. Typically, the higher the number of the components and the more complex the structure of the products, the higher the rigidity of the disassembly sequence that should be followed. Otherwise, the products might be damaged during disassembly. A manager described this issue like this:

'There's a standard worksheet that mentions disassembly in a specific order and that's developed specific for individual engine because it depends on the complexity of the engine. So yes, it's specific and all dictated, things are done in certain orders'.

In terms of (PA4) level of disassembly, the company carries out full disassembly instead of partial or selective disassembly. Full disassembly is one of prerequisites so that other processes in remanufacturing like cleaning, testing and inspection can be carried out. This situation is described below by one of the respondents:

'But in actual fact to get down to the needed the material, you've got to ***completely dismantle it*** *which takes a lot of time and effort. And often you have to do things after the cleaning and again put working to it'.*

Automotive engines do not have a (PA5) wide variety of materials because it is largely made of metal based materials. As such, all the components require homogenous treatment and there is not any specific treatment required due to its sensitivity (i.e. cannot be touched, need certain temperature, heating etc.). The materials include iron based alloys such as structural steels, stainless steels, iron based sintered metals, and cast iron. Other materials are like aluminium alloys are also used for piston, cylinder head and cylinder block. Some minor components like bearings are made of rubber that is prone to damage as it is not as robust as metal based materials. However, the components have to be replaced, and destructive disassembly is possible for these components.

In some sub-modules with a high (PA6) number of components, further disassembly is certainly needed. This is due to the fact that the company cannot carry out inspection unless the components are disassembled. The more complex engine structure that is indicated by the number of components, the more specific the sequence of the disassembly, as mentioned by the interviewee:

'Yes, there's a standard worksheet that mention disassembly in a specific order and that's developed specific for individual engine because it depends on the complexity of the engine'.

The adoption of (PA7) ecodesign principles seems very limited. OEMs very rare consider their products for remanufacture. This condition is indicated by the high number of product variants. Once the products have been disassembled, they need to be classified by further details. This condition requires the company to prepare more equipment with different purposes. The situation is described like this by one interview:

‘Some engines have over 20 variants. And they are coming, generally speaking, very generic part number levels and then you have to identify exactly which one of these. And then you have to say: no, that one never to be in group with this one but yes with that one. I have to take them two apart and make them different at the end of the results. So they would basically do very manufacturing by service because it's so dictated by the equipment they had available’.

During the company visit and conversations, (PA8) the use of smarts technologies like active disassembly to make the process easier was not found. All disassembly activities are carried out manually without any high technological assistance.

6.3.4. Analysis with existing studies

Table 6.3 aims to highlight the key findings to answer the first research question from the narrative description above. Given the first research question is deductive in nature, the relevant literature related to the findings is also presented to connect with existing findings.

Table 6.3. Analysis of findings in Company C with existing studies

No.	(CODE) Factors	Result of analysis	Key findings from this case and relevant literature
Organisational characteristics			
1.	(OC1) Degree of the relationship with OEMs	Confirm	As a contract remanufacturer, Company C maintains relationship with the OEMs through contracts to ascertain the supply of cores as the raw materials and to reduce uncertainties. This finding confirms the idea of Ijomah (2009), Lind et al. (2014) and Saavedra et al. (2013)
2.	(OC2) Knowledge transfer from OEMs	Confirm	The contracts with OEMs can help the company to acquire knowledge regarding know-how about the products and remanufacturing operations(Ijomah 2009; Saavedra et al. 2013). This finding is line with existing study that found assistance from OEMs could be useful to develop specific equipment to reduce cost (Westkamper 2003).

3.	(OC3) Size of the remanufacturer	Confirm	Size of Company C expands into bigger size due to contractual agreements with OEMs. The contracts make the company bigger in size due to expansion in production capacity. This finding is in agreement with (Lund 1984) who states that remanufacturers typically are bigger than independent remanufacturers. More recent studies also confirm these findings (Seitz 2007; Seitz & Peattie 2004)
4.	(OC4) Cores sorting	Confirm	Cores sorting organised in this company support existing literature which states that it can be used to reduce cost of disassembly, labour time and reducing risk of handling hazardous substance (Simolowo et al. 2011).
5.	(OC5) Use of product information database	Unconfirm	Managers can use the information from database to track the parts that need for replacement. However, this is only useful for products that are remanufactured more than once (Ketzenberg et al. 2003). Automotive engines remanufactured in Company C are rarely come back to the company and consequently product information database does not offer much benefit to the company.
Process choices			
6.	(PC1) Make-to-order versus make-to-stock	Confirm	Company C organises combined MTO and MTS but the proportion of the former larger than the latter. These evidences support existing works that explain smaller companies are able to respond demands from the market more easily so that MTO is more preferred (Ketzenberg et al. 2003; Tang et al. 2007). To support MTO strategy under stochastic demand condition, the company adopts considerably accurate forecasting as suggested by (Li & Rong 2009).
7.	(PC2) Volumes of cores supplies	Confirm	Company C prefers high volume of cores supplies because it can be disassembled in batch and gain economic benefit. This evidence confirms the work of Guide and Wassenhove (2001). Another benefit of high volume core supplies is that they can better support employee learning rather than in smaller cores volume (Jaber & El Saadany 2011).
8.	(PC3) Specific versus general tools and equipment	Confirm	Tools and equipment in the company are customised design and developed in house but the rest of them are partly general purposes. In general, this finding is in line with Guide et al. (2005) who state that remanufacturers tend to use general equipment. The use of automated disassembly using specific equipment is not feasible economically because there is no complete cores information (Harper & Rosen 2001) and high variability of cores condition.
9.	(PC4) Generic versus specialized skills	Confirm	The company attempts to build some degree of specialised skills through a 3-1-3 scheme to facilitates learning and obtain specific skills. In remanufacturing, learning to develop specific skills has been proposed in the work of Martin et al. (2010). The specific skills can reduce remanufacturing cost, disassembly time and the need for part replacement (Chiodo & Ijomah 2012)

Product attributes			
10.	(PA1) Value of recovered products	Confirm	This case study corroborates the opinion from Westkamper et al. (1999) Li and Rong (2009) and Ferrer (2001) who state that the right decision to recover depends on the economic factors and conditions of end-of-life parts. Automotive engines remanufactured in Company C have considerable high value parts and long life. Long life products make the company more interested to invest a larger amount of money in order to set up a facility and train the employees for disassembly tasks.
11.	(PA2) Functional versus innovative products	Confirm	Automotive engines remanufactured in the company have a considerably long life and relatively stable residual value. These conditions enable the company to spend financial resources for investment in both people and the disassembly facility. These evidences confirm of Subramoniam et al. (2009) and Ijomah et al. (2007) arguing that products should have long life and high residual value. These will offer sufficient economic incentives for remanufacturers (Chiodo & Ijomah 2012).
12.	(PA3) Sequence of disassembly	Confirm	Automotive engines can be disassembled in some different ways but Company C has decided that disassembly should be conducted using a certain sequence to increase efficiency and minimise number of damaged components. Findings confirm the opinion of Smith et al. (2012) who argued that selecting optimum disassembly sequence can reduce disassembly time.
13.	(PA4) Level of disassembly	Confirm and extend	Optimal level of disassembly is affected by the benefit obtained from disassembly and cost of disassembly. The cost consists of (1) tolling and labour, (2) material reprocessing cost, i.e. cost of recycling, (3) disposal cost such as transportation and landfill costs, and salvage profit (Zhang et al. 2004). Company C does not attempt to find optimal level of disassembly. Rather, the company disassembles completely all cores because the cost difference between full and partial disassembly is not significant.
14.	(PA5) Type of materials	Confirm	Materials of automotive engines mostly consist of metal. This evidence confirms the finding of Gerrard and Kandlikar (2007) who found that as much as 75-80% percentage of vehicle materials are made from metal. Metal-based products can be disassembled without damage and then remanufactured that result in products with the same quality as the new one. These findings confirm the work of Go et al. (2011) who argued that the type of materials affect the process of remanufacturing including disassembly. Relatively homogenous types of materials make disassembly process easier (Feldmann et al. 1999)
15.	(PA6) Number of components	Confirm	This case reveals that number of components affects product complexity while complex products require more rigid criteria during disassembly. These findings confirm the work of (Zwolinski & Brissaud 2008) who found that higher number components leads to a more complex disassembly process due to its more rigid guidance that eventually reduce the diassemblability of the products.

16.	(PA7) Ecodesign principles	Unconfirm	This case study demonstrates that ecodesign and technological development might contradict one another. It seems that the manufacturers emphasise on the technological development rather than ecodesign. This can be explained with an explanation from Zwolinski and Brissaud (2008) stating that technological development in some way may hinder disassembly and remanufacturing.
17.	(PA8) The use of smart technologies	Unconfirm	The use of smart technologies like active disassembly as suggested by Chiodo & Ijomah (2012), Chiodo et al. (2002), and Ijomah & Chiodo (2010) to assist disassembly workers is not found. Possible reasons could be that the volume for each product model is not large enough to afford technology development (Duflou et al. 2006) or it is still expensive at present time (Sundin et al. 2012).

6.3.5. Some highlights of the findings

The following is the summary of the qualitative data organised into major themes following the suggestion of Maxwell (2005). The following points are the summary of strategies adopted in Company C to manage its disassembly resources so it can run smoothly. To achieve this purpose, the company:

- ***Minimises idle capacity due to high volume of production.*** The company utilises production levelling to distribute production evenly across different periods. Reducing idle capacity is important since the company spends a large amount of fixed cost investment to set up the facility.
- ***Classifies the components based on their families.*** The components need similar processes are categorised in the same group and moved together afterwards. The purpose of this is to minimise cost of movement.
- ***Develops a formal procedure to carry out full disassembly supported with documents.*** Although automotive engines can be disassembled in different sequences, the company formal procedures that should be followed by the employees. This technique results in efficient disassembly time.
- ***Develops employee skills matrix to allow job rotations.*** Company C adopts a 3-1-3 scheme for employee skills so that the employees have specialised skills but still can be rotated in some ways. The job rotation allows the company to better allocate the employees while some degree of specialised skills enable them to work more efficiently.
- ***Provides training to new employees.*** Before the employees are eligible to carry out the disassembly task, they have to undergo formal training, then work to serve somebody, do the same job alongside somebody else, do the job but under supervision of a more senior employee, and finally become eligible to perform the job independently.
- ***Utilises some customised design tools and equipment that are operated by skilled employees***. The customised tools and equipment are used to meet the specific purpose of disassembly tasks. To operate the tools and equipment, the employees are trained so that they can do the disassembly tasks in a very efficient way.
- ***Spends high investment to set up dedicated disassembly shop floor.*** The investment covers spending to develop tools in-house, employee training, and develop formal procedures for disassembly. The factory organises its facility using a cellular design and a dedicated shop floor for disassembly.

- ***Disassembles in large batch and high production volume***. This strategy aims to minimise the fixed cost coming from investment in the infrastructure such as building customised tools, equipment, and training for the employees. To achieve this purpose, the company is supported with contractual agreement from OEMs as cores suppliers, a large number of cores stocks to ensure the availability of raw materials and production levelling.
- ***Maintains stock of cores at a certain level during the contract periods.*** Finished products will be dispatched as soon as they have been completed. Stocks are available at almost every stage of remanufacturing process as part of production levelling strategy.
- ***Carries out forecasting to develop robust production planning and scheduling***. This strategy is used to minimise idle capacity and enable the disassembly shop floor to operate in an efficient way. The company organises joint forecasts with the customers to develop production planning so that inefficiency due to time uncertainty can be minimised.
- ***Organises cores sorting***. The company attempts to avoid low quality cores from entering the disassembly facility since it may cause disruption during disassembly. For example, rusty nuts and bolts may become sticky and difficult to separate. This can cause some disruption on the flow of disassembly on the shop floor.
- ***Carries out full disassembly.*** During disassembly sometimes there are some components that have to be disassembled destructively. The full disassembly is needed to make other processes in remanufacturing possible.

6.4.Company D

Company D started as a remanufacturing business for photocopiers in 1994. In 2011, the company was acquired by Xerox, a global photocopier manufacturing company. Other than managing its facility located in Glasgow, the company office in Glasgow manages another facility located in Aberdeen.

The company is supported with its own reverse logistics team that collects cores from customers and distributes remanufactured photocopiers. Its customers, who are mostly industrial customers, develop a relationship with Company D based on a leasing agreement. With the support of 43 employees, the company delivers approximately 40 remanufactured photocopiers per month from a wide range of models. Although most photocopier models can be remanufactured, the company remanufactures the most popular and reliable models only.

6.4.1. Organisational characteristics

In terms of (OC1) the relationship with OEMs, Company D is an OEM remanufacturer because it is subsidiary an OEM specialising on remanufacturing business. All the cores supplies are obtained from the customers who sign leasing agreements with the company. Cores arrive at the facility in more predictable manner because the circulation of the photocopiers forms a closed-loop chain. The company leases the products and forecasts the cores arrival based on the launch of the new products. The manager described how the business works as follow:

'The average of the new box machine is almost 100 new box machines per month. That also for us and for remanufacture is that it is the foundation for the future of remanufactured machines. If we put now 100 new machines, in 2.5 and 3 years time, we will have 100 second hand machines coming back through that we would like to remanufacture. In that stage maybe 50-60 at the moment'.

There is (OC2) knowledge transfer from the OEM, which is the parent company, to Company C that organises remanufacturing, and vice versa. One of the respondents explained an example of how the OEM supports and how the company supports the OEM as follow:

'The manufacturers will release technical bulletins and stuff like that for modifications as well. So if they find any parts will need modifications they'll let us know about any parts. We'll let them know with certain things. Sometimes they'll let us know before we even know about it'.

'I think they bought us from a business perspective and business model and look at us and say this is how we can make some more profit to go back to my visit. I like to go and see what other people are doing in remanufacturing because I know obviously what we do, I want to learn from them and their way that we can learn from'.

The (OC3) size of Company D increased significantly after it had been acquired by Xerox in 2011. Due to the acquisition, the volume of remanufactured products in the company has increased by 25-30 per cent. The cores come from new products that are sold to customers by Xerox and subsequently come back to Company D. Before the company was acquired by Xerox, it had a lower volume of cores supplies.

Company D carries out (OC4) cores sorting to assess the condition of the cores. The purpose of the sorting is to (1) avoid photocopier models that are not suitable for remanufacture, (2) assess the potential cost to remanufacture, and (3) estimate the potential selling price of the remanufactured products. For the first purpose, the company can avoid cores before they arrive at the facility. Photocopier models not working well in the past will only cause problems in the future if they are remanufactured, so that they are not.

There is an instrument attached to photocopiers that provides a historical use of the products. Nevertheless, the data from the instrument is not accumulated into (OC5) product information database; the information is used only for disassembly for that particular product. How the instrument can be useful for disassembly and remanufacturing in general is as follows:

'*…there is an electronic meter that will tell you how many A4 sheets, how many A3, how many scan, how many prints, how many prints you have sent to it, because it's a MFD, multifunctional device*'.

In addition, the technology embedded in the product could also give the engineers history of use of the products:

'We can go in electronically and interrogate the machine. So, we can go into engineer access code, and say tell me the life that the drum has done. Tell me the life the fusion section has done, and how many paper jams the machine has done, tell me when these paper jams have occurred in the machine. So, it gives us areas to address'

These technologies assist the employees to decide whether the components should be replaced with new ones. The company decides to reprocess and use the component again if the the remaining value is high. This decision is important in disassembly since recovered components will require more treatment during the post-disassembly process (e.g. handling and moving) in comparison with rejected components. In addition, for rejected components there is no need to worry if there is any damage during disassembly.

6.4.2. Process choices

Company D combines (PC1) MTO and MTS with the former being more dominant than the latter. The purpose of the dominance is to minimise inventory close to zero. To support this aim, the company currently builds a facility where all activities could be undertaken under one roof and this therefore results in more efficient operations. Regarding to what extent the company could achieve the target of zero inventory, the respondent explains as follows:

'Yeah, well we're trying to have more or less. As I said maybe 90% and if you had all over those spares by your side and you finish the machine'.

Components availability is the constraint to apply MTO totally. Orders could be met using MTO operations but the availability of the components makes it difficult to fulfil the orders. The delivery would be delayed due to this constraint. To overcome this, the company still has buffer stocks as an anticipation when the customer orders are received. The company on average holds stocks of 25 units from a wide range of models. This figure is considered low given that there are wide ranges of photocopier models remanufactured in this company.

Company D could manage the (PC2) volume of cores supplies well since it obtains cores easily from customers. The company attempts to manage volume of cores supply so that it does not either fall below or above its capacity. To do this, the company carries out robust production planning and scheduling. The closed-loop supply chain in this company makes the forecast easier since the new products launched by the company would come back to be remanufactured. The forecast of cores supplies is carried out based on the volume of new products sold to customers.

Regarding tools and equipment, the workers use (PC3) general tools and equipment during the disassembly process. All tools and equipment required to carry out disassembly can be obtained in market place. The workers need more tools and equipment during handling and moving the components after the cores have undergone the disassembly process. Due to the sensitivity of some components, some treatments are needed during handling and moving in the post-disassembly process. For example, there are roughly 20 sensors in photocopiers depending on the model. The sensors are small and fragile, so they cannot be mixed with other components during handling and moving. Another example is an OPC (Organic Photo Conductor) drum that is not allowed to be touched. This brings consequences that some components require different treatments and equipment.

Not everyone in the company can hold a position as a disassembly staff member. The employees tend to have (PC4) specific skills rather than general ones. The manager describes that a good candidate to hold the position is that he should have a mechanical aptitude, a good memory and be a logical thinker. An engineering degree or experience in another position that deals with mechanical products would be a good start. When he was asked whether any person could occupy the position, he responded:

'No, I would say that if you get someone with good mechanical aptitude then that would be a really good starting point for us to have them doing that type of job'.

'Because, yeah for this type of job you have to have a really good memory. If you have a good memory it's great because you can remember how things work. If you've a good mechanical aptitude because you can remember when you're stripping something down how it goes back together again'.

Further, using an example, he explained how the logical mechanical aptitude is necessary to carry out disassembly in photocopiers:

'Two latest people we employed come from an engineering background. Erin, she spent 6 years in the Royal Navy. She was an engineer in the Royal Navy and she is come on, so pulling from an area that is familiar with electromechanical. They know how to handle tools; so have that set of skills initially. So they knew how to handle tools, they know how to assemble and disassemble. They knew if they look at something, if that gear turns that way, then seven gears down and other that one will turn that way'.

6.4.3. Product attributes

In general, the potential (PA1) value of recovered products within photocopiers is considerably high. For Company D, the opportunity to recover the potential value is high since the company does not have to buy the cores. Here is a description from the manager regarding the value of recovered cores:

'That's the point when the machines come back from customers to us at zero cost. So we don't know whether we have to go to the market and buy it at 576 pounds. When it comes

back at zero cost, the cost that is attached to it is remanufacturing cost. So the parts that we put on it, time and labour that put into it is the cost'.

Based on the description above, the potential recovered value exceeds the cost of disassembly and remanufacturing cost. This is because expected selling price is considerably higher when compared to the acquisition cost of the cores. In certain cases, when the photocopiers are not remanufactured, the company decides to undertake selective disassembly to recover high value components only. Here is an example:

'If we see that the drum has 40 per cent of its life and the copy quality is good then we are not gonna replace it, because what's gonna happen is we gonna go to customers and when the drum becomes reach the stages end of its life, or the copy quality deteriorate, then our field engineer will go and replace that, so we have to check the customer and service. But if we want to replace it and 40 per cent of its life then basically we throwing 40 per cent of the value of that drum which doesn't do anything to anyone'.

Some of the photocopier models are innovative, but most of them are (PA2) functional products. The constraint of how many times photocopiers could be remanufactured is not the obsolescence of the products, but rather the new parts availability. The products could be remanufactured many times but remanufacture should stop when there is no longer a supply of new parts from manufacturers. After 8 years from the product launch, the manufacturer is no longer producing new parts needed for the models and this therefore hinders the company to carry out remanufacture.

There is a work instruction that explains a specific (PA3) sequence of disassembly. The instruction explains which modules or components should be taken before others. When the manager was asked whether disassembly could be carried out in any sequence, he replied:

'No, we have a specific direction to do it. The guys will have a work instruction and it will be whatever it is per model. All the panels off then the fuser section out, the transfer section out, the paper feed sections out, this, this, this. Then address all of the sections and then rebuild. So yes, we do have a process and a procedure'.

The company attempts to find the optimum (PA4) level of disassembly to improve disassembly efficiency. The photocopiers are not disassembled completely; rather they are disassembled to a level at which remanufacture can be carried out. All the modules are taken out from the chassis and then the components are taken out from the modules. Nevertheless, not all components are taken out from the modules. In other words, the machines are disassembled completely at module level but the modules are not stripped off completely into the lowest components. The modules are disassembled to a level at which cleaning and testing can be undertaken. Some modules cannot be broken down into components because if they are disassembled it means breaking them.

(PA5) Type of materials for photocopiers is quite diverse and they mainly consist of steel, plastics, glasses and other materials. The variety of materials requires different treatment during the physical disassembly activities and the post-physical disassembly activities. For example, materials made of plastics are lighter but they are easier to scratch than those made of steel, particularly during moving and handling. Similarly, a censor requires different treatments, as they are made from plastics, are sensitive and could be broken easily.

Different product models have a different (PA6) number of components with higher product specifications having more components. All photocopiers essentially work in the same way and consist of similar modules regardless of the models. For example, the Xerox WorkCentre 7556 family, which is one of the popular models among customers, has component numbers as high as 3,032. These components constitute modules including a paper cassette, paper feed, registration roller, exposure lamp, OPC (Organic Photoconductor) drum, charge corona, toner unit, fuser unit and some others. These modules are always found in any model since these are the main constituents of photocopiers. Due to this high number of components, the disassembled components require grouping during moving and handling. This occurs during the post-physical disassembly activities.

Interesting evidence was found in the adoption of ecodesign principles. Although the Company D is part of an OEM, there is no clear information regarding the (PA7) adoption of ecodesign in photocopiers. The respondent admitted that the photocopiers get easier to remanufacture compared to years in the past, but he was not convinced if it was the intention of the OEM to do so. Here is his expression:

'But I would say that they're much more friendly now in terms of remanufacture. I don't know if the manufacturer is deliberately going down that route or it just happens to be the case. As possibly the copiers are becoming about more routine maybe and some assemblies in there don't have to be too intricate and ease of access is a little bit better'.

There was not any specific (PA8) smart technology attached to photocopiers that could assist disassembly. Disassembly was carried out without any assistance of advanced technologies like active disassembly that can help the employees to disassemble.

6.4.4. Analysis with existing studies

In this section, empirical findings that have been presented in narrative discussion above will be analysed with existing studies. The purpose of the analysis is to examine whether evidences confirm, unconfirmed or extend existing studies.

Table 6.4. Analysis of findings in Company D with existing studies

No.	Factors	Result of analysis	Key findings from this case and relevant literature
Organisational characteristics			
1.	(OC1) Degree of the relationship with OEMs	Confirm	The findings confirm existing literature. As an OEM remanufacturer, Company D has better access to cores compared to contract and independent remanufacturers (Sherwood et al. 2000). In addition to this, leasing agreements with customers cause the cores arrival become more predictable and manageable (Lind et al. 2014; Östlin et al. 2008).
2.	(OC2) Knowledge transfer from OEMs	Confirm	As part of OEM, the Company D receives supports from the manufacturing division of its parent company. The supports include information regarding product design and standard of new product (Lind et al. 2014). This support can help the company to reduce costs (Westkamper 2003).
3.	(OC3) Size of the remanufacturer	Confirm	Size of Company A increases after it has been acquired by Xerox. The company can expand because it has better access to cores and gain supports from the OEMs (Ridley 2012; Ijomah et al. 2007). These findings confirms existing literature explaining that remanufacturers that are related to OEMs typically have bigger size (Seitz & Peattie 2004; Seitz 2007).

4.	(OC4) Cores sorting	Unconfirm	Company D does not organise cores sorting as suggested in literature (Tagaras & Zikopoulos 2008; Zikopoulos & Tagaras 2008; Loomba & Nakashima 2012; Galbreth & Blackburn 2006; Sundin & Bras 2005). Most of incoming cores are processed either to be remanufactured or to recover valuable components only. All products are inspected to assess what components need to be retrieved and recovered.
5.	(OC5) Product information database	Confirm partially	The findings partially confirm existing literature. Yang et al. (2009) demonstrate that an intelligent device can be used to identify pattern of product use. Data regarding pattern of use is useful for remanufacturing (Chung & Wee 2010) and this evidence was found in Company D. However, the data from the products use was not integrated into overall product information database as suggested by Westkamper et al. (1999).
Process choice			
6.	(PC1) Make-to-order versus make-to-stock	Confirm	Company D adopts MTO to respond demand from market. This finding confirms previous study which shows that adoption of MTO can adapt more easily to market (Ketzenberg et al. 2003; Tang et al. 2007). To support MTO, company D carries out considerably accurate forecasting because it is a critical success factor in stochastic condition (Li & Rong 2009).
7.	(PC2) Volume of cores supply	Confirm	Company D obtains cores easily from customers so that volume of cores is not an issue for the company. The manager admitted that a sufficient volume of cores supplies is needed to ensure economic efficiency in disassembly and this confirms the work of Kerr and Ryan (2001). The company can gain higher economic efficiency if it receives cores in higher volume. For example, Chiodo and Ijomah (2012) develop a scenario to produce as many as 500-5,000 products per minute whereas Franke et al. (2006) require 5,000 cores of mobile phones per day.
8.	(PC3) Specific versus general tools and equipment	Confirm partially	Theoretically, products with a high number of unique components require specific tools to disassemble. But the volume of disassembly which is not high makes use of specific tools and is not feasible economically. For this reason, the employees who disassemble cores mostly use general tools and only small portions of customised tools needed. This allows tools and equipment sharing between different product models (Ferrer & Whybark 2001). Flexibility of the disassembly facility which is reflected in the ability to adjust with demands with a short time for set up is a critical success factor demanded by customers (Westkamper 2003).
9.	(PC4) Generic versus specialised skills	Confirm and extend	The workers are equipped with specific skills to disassemble and remanufacture certain product models. The employees are transferrable for different phases of remanufacturing but not for different product models. The skills are developed in-house within the company since there is not any training provider or formal education that provides the training. These findings affirm the idea of Williams et al. (2001) who argue that in smaller remanufacturing companies, typically one employee undertakes all the remanufacturing tasks by himself. But in this company, the employees should also have talents to memorise how things work and a good mechanical aptitude. Without these, the candidate will not be able to work effectively.

Product attributes			
10.	(PA1) Value of recovered products	Confirm	The company does not have any concern with the value of returned products. The evidence supports the literature that the yield from cores is uncertain (Ferrer & Whybark 2001; Ilgin et al. 2011; Ferrer 2003; Westkamper et al. 1999) but disassembling the cores is profitable in most cases. This is because the ratio between the acquisition price and the value after the cores have been disassembled (Li & Rong 2009) is consistently high. In this case study, the cost of cores acquisition is zero. Once the cores have been disassembled and remanufactured, the finished products could have a high price, one of the key success factors of remanufacturing (Kerr & Ryan 2001).
11.	(PA2) Functional versus innovative products	Confirm	Innovative products that have short life are less suitable for remanufacturing because they will become obsolete in a short time (Tagaras & Zikopoulos 2008; Ijomah et al. 2007a). The finding from this case company confirms this statement because photocopiers could be remanufactured two or three times during 8 years before the OEMs discontinue the supplies of new parts.
12.	(PA3) Sequence of disassembly	Confirm	The findings demonstrate that the company has prepared disassembly sequence planning for each photocopier models. These findings accord with earlier observations in different ways. The sequence is important to minimise damaged components (Adenso-Díaz et al. 2008). It also maximises the value of recovered components since different components add different value to the final products (Ferrer 2001). In addition, disassembly planning is important to minimise resource expenses and maximise the quality of recovered materials (Lee et al. 2010; Ferrer 2001; Moore et al. 1998).
13.	(PA4) Level of disassembly	Confirm	The company attempts to disassemble to the lowest possible level under which remanufacturing can be carried out. These findings accord with Ferrer's (2001) work which demonstrates that not every component can be disassembled into the lowest parts since the components would be broken if the company was to do so. Furthermore, Ferrer (2001) suggests to recover the more valuable parts and reject less valuable parts in case this happens.
14.	(PA5) Types of materials	Confirm	The materials of photocopiers are quite heterogeneous but there is not any hazardous material that might endanger the employees during disassembly. Consequently, as suggested in the work by McGovern and Gupta (2007), the company does not need special handling equipment to avoid the risk. However, due to the different types of materials used, some components need more attention during the post-physical disassembly activities. For example, components made from plastics, which are more sensitive to scratch than metal-based components. These components need more attention during post-physical disassembly activities.

15.	(PA6) Number of component	Confirm	The evidence confirms that the number of components is associated with disassembly. Number of components, precedence relationship and joining methods are among the information required before disassembly is carried out (Zhang et al. 2004; Tang et al. 2002). Since 50% of disassembly tasks are disconnecting joints that consume more than 50% of the total disassembly time, a higher number of components imply a longer time to disassemble. All of these tasks are complex processes due to the high number of variations of the tasks (Westkamper et al. 1999).
16.	(PA7) Ecodesign principles	Unconfirm	The company admitted that more recent models of photocopiers are easier to be dismantled but it is not confirmed whether the manufacturer does this deliberately. This phenomenon can be explained using the argument from Ferrer (2001) who states that design for assembly might support disassembly coincidently.
17.	(PA8) The use of smart technologies	Unconfirm	There are some instruments embedded in the products. But the devices are intended for supporting other processes in remanufacturing in general – i.e. to decide whether the cores should be rejected or reused, or to estimate the remaining life of the components. There is no specific device to support disassembly and make disassembly more economically beneficial.

6.4.5. Some highlights of the findings

Following the suggestion of Maxwell (2013), rich qualitative data that has been presented above should be summarised to highlight the major themes found in the case. The following points are the summary of strategies adopted by Company D to manage its disassembly resources so as the disassembly can run smoothly. To achieve this purpose, Company D:

- ***Attempts to maximise reclaimed value of cores.*** Streamlining material flows is less important than optimising the value of recovered components. The reason to maximise reclaimed value is that the components have a high residual value.
- ***Classifies the components based on the characteristics and uses separate equipment to handle and move them.*** Photocopiers are made of different materials that have a different nature. In addition, there are many components that are small in size and are sensitive, for example, sensors that are small in size and fragile. These components should be handled and moved separately from others.
- ***Determines a general sequence under which disassembly should be carried out.*** In addition to this, there is a specific sequence for different models of photocopiers. Both the generic and specific sequence should be followed so that all the components can be recovered easily during the rebuild process.
- ***Conducts employees rotation but at a limited opportunity***. Employee transfers are possible between different processes in remanufacturing but the transfer is not possible between different photocopier models.
- ***Employs disassembly operators that have relevant formal qualifications, relevant work experience and mechanical aptitude***. Not all employees in the company are eligible to hold the

position as a disassembly worker. A good candidate should have a degree in engineering, relevant work experience that deals with machinery and a good mechanical aptitude.

- ***Utilised general tools to disassemble***. Tools and equipment are readily available in the market so that the company does not need to develop customised tools.
- ***Sets up a facility to maximise the value recaptured from the cores***. The facility includes equipment to interrogate the machine electronically, training for the employee, update the skills of the employees to disassemble, and recruit the best available people to occupy the position.
- ***Disassembles in units, not in batches or lots.*** There are good demands for remanufactured products and all of the products are sold easily to market. If there is an employee on holiday, there will be a significant reduction on production volume. This is because one employee works on a core from start to finish and each employee could remanufacture different photocopier models.
- ***Attempts to adopt a zero inventory for remanufactured products.*** The company can obtain cores very easily so that stocks of cores are built as anticipation of unexpected demands. The company needs to anticipate what photocopiers model that will be demanded because there is a wide variety of models.
- ***Relies on historical data to forecast what models the customers usually request.*** A small deviation on the production forecast can cause a large amount of cost spent. The production planning is mostly developed based on historical data and the company disassembles the cores in units rather than in batches.
- ***Disassemble cores that are suitable to be remanufactured***. Type of the photocopiers that will cause problems during the leasing period can be predicted. All cores can be disassembled and remanufactured but the company only selects the most profitable cores for remanufacturing. For cores that are not suitable for remanufacturing, the company disassembles them and retrieves certain components for cannibalisation.
- ***Undertakes disassembly into the level under which the cores can be remanufactured***. The cores are not disassembled completely since some of the modules will be broken if they are disassembled completely.

6.5.Company E

Company E is one of branches of a leading jet engine manufacturer that focuses on remanufacturing. All remanufacturing activities conducted in this company are part of leasing agreements with airline companies based on power-by-the hour. Under this agreement, the company still holds some sort of ownership towards the engines installed in the airplane operated by customers. The customers are highly diversified consisting of 120 customers ranging from commercial, government and military sectors, with production volumes approximately 400 engines per year.

6.5.1. Organisational characteristics

The company has a strong (OC1) relationship with OEMs since the company is a branch of the manufacturer that build new jet engines. It is the parent company that manages the cores supplies and delegates the remanufacturing activities to Company E. The company obtains cores from airline operators that sign contacts with the parent company and the parent company authorise Company E to remanufacture. Under this business agreement, the company creates barriers to entry for competitors that result in easy access to cores. This situation is described by one of the managers like this:

'...because we restricted them, who else could overhaul our products. So, if you look at Trent 700 engines, probably 90% of them are around power-by-the hour contract. So, it's quite small amount for someone else to go after and try to win 10%-15% of the market, it's not worthed'.

There is a lot of (OC2) knowledge transfer from the OEMs. There are methods that can be obtained from the manufacturing company such as how to set up standard of quality, assemble, and test the products. However, the specific information for disassembly is not available and the company has to develop the facilities from scratch since remanufacturing process is different from manufacturing one in many ways. One of the most important supports from OEM is engine manual that is provided to Company E. The manual contains detailed information regarding jet engines specifications that cannot be obtained by third-party remanufacturers which do not have relationship with the OEMs.

(OC3) Size of the remanufacturers is a critical success factor to develop disassembly facilities for jet engines. It is very hard for small sized companies to develop disassembly facilities since they require high cost investment both for physical (i.e. tools, equipment and factory) and non-physical infrastructure (i.e. skills, technology and human resource).

Company E does not organise (OC4) cores sorting because the company is supported with Engine Health Management System (EHMS) whose function is similar to cores sorting in several ways. Much like to core sorting which can reject low quality cores, EHMS also does a similar thing. A manager described the benefit of EHMS as follows:

'...and the best thing you would do is being intelligent. If you know that there is a chance that certain part is gonna be required for the engine then you wouldn't induct it'.

In this case, the EHMS function is as a gate keeping to avoid the company from accepting low quality cores. This function is similar to cores sorting in which low quality cores that are too costly too to be remanufactured are rejected. The EHMS also give data regarding vibration, where parts that need replacement can be identified as early as possible even before the engines arrive at the facility.

The company utilises (OC5) product information database to manage uncertainties due to the high number of components coming from jet engines. The information predominantly comes from two sources: EHMS and the engine log-book. The two sources have different functions. EMHS records information regarding the performance of the engines during operations. Based on this information, some prediction can be made pertaining to the type of potential damages, the need for part replacement, and eventually which modules need for disassembly.

With the use of EHMS, uncertainties regarding which components should be taken out, and what type of components need for replacement can be identified, and thus, to some extent the level of disassembly can be estimated. In other words, uncertainties in disassembly can be reduced and unnecessary work can be avoided with information gathered from the EHMS. Different from the EHMS that record data during operations, the log-book records the history of the engines in a longer period including any modification that has been done by the airline operators.

6.5.2. Process choices

The company organises (PC1) made-to-order production system based on orders from the customers. The orders come from airline companies that have leasing agreements with the company based on power-by-the hour, an agreed fee with the airline for how much cost for an engine to fly for one hour. Due to high value and high number of components, the company needs to develop robust production planning and control supported with a reliable forecasting technique. Unreliable production planning and control leads to a high number of inventory and inefficient disassembly process as described by the manager here:

'So you need to be very, very good at forecast so that's why sometimes we induct, we've got very high inventory [of components] *because we have ordered in advance, and then we burn the stock off'*

The (PC2) volume of cores supply affects disassembly in some ways. An appropriate volume of cores supply is useful to streamline material flows during disassembly so that idle capacity can be avoided and therefore result in a better resource allocation. In addition, disassembling a number of engines is more beneficial rather than disassembling single engine only. In the case that the company does not have required components, an engine can 'borrow' some components from another. The strategy is undertaken in case there is a long waiting time of new components from suppliers. 'Component borrowing' can be carried out provided that the owner of the engines is the same party.

Another benefit of sufficient volume of cores supplies is that it can help employees to attain and maintain certain qualifications. These qualifications cannot be maintained unless the employees carry out the tasks. In other words, the skills can increase and decrease in line with the supply of cores. The manager describes the situation like this:

'When we train you in the fan module, this is the skill that he must be able to demonstrate, and that would be class room training, it will be his skills that refer to verifying his documentations, his instructions, his compliance to that instructions, and every three years we go through a reaccreditation to make sure that you still have that skill, you still displayed that skill on a number of occasions during that three year period and you'll become reaccredited. So, it's an ongoing and iterative process'.

Different from in remanufacturing companies in general, (NEW) employee qualification in Company C is a critical requirement as it is a mandatory requirement from regulatory bodies such as the CAA (Civil Aviation Authority) and IASA (International Aviation Safety Assessments) and EASA (European Aviation Safety Agency) which monitor how the company develops, trains and maintains the capability of its employees.

(PC3) Tools and equipment are strongly related with (PC4) skills and knowledge of the employees. The manager below describes the tools, equipment, skills and knowledge required for disassembly like those in the operating theatre where a surgeon is working on a patient with the assistance of nurses.

'...all disassembly process is like a surgeon in the operating room. When the surgeon in the operation room, and he's build a turbine disassembly, he should be put his hand out like this [he put one of his hand behind his back], *and the assistant, the nurse behind him, give him the tools that he needs to disassemble, he do that again to get the next part to disassemble. You'll never see this surgeon's walking away from the patient, he stands there, he's got six other helpers who's going to get all the equipment, he is totally focus on that patient and the person who is the assistance, the nurse in the operating theatre, she has been trained with the tools behind and he* [the surgeon] *asks for that tool, she reaches that tool and give him the next tool'.*

He admitted that the current condition in Company E is not ideal as that in the operating theatre but he attempts to make the condition as efficient as possible.

6.5.3. Product attributes

Jet engines have high (PA1) residual value coming from both the materials and the manufacturing process. The materials of jet engines are mostly high grade titanium, which has high economic value. In case there is any rejected part, every single piece of the precious part is collected to recover the value from the raw material – i.e. titanium. The main attention is to be given to maintain the high residual value coming from the manufacturing process so that is not degraded. This is explained by the interviewee:

'The biggest problem is to ensure that, if you're looking maybe high cost components that enough thought has been given to ensure that the tooling will not damage the parts. So, I'll give you an example. If you're making a turbine disk, a turbine disk could be 300,000 pound sterling. And then if you join two disks together and the tools, the socket that you use cuts the disks, you could put a mark on the disk, you can scratch that disk'

Jet engines tend to be (PA2) functional products rather than innovative products considering their extremely long product life. Their life can be up to as long as 30 years and can fly 50 million miles during their lifetime. For these reasons, the engines have relatively stable residual value over time, making them feasible for remanufacturing. In addition, high fixed investment costs to set up the facility can sustain disassembly operations for a considerable long period.

In Company E, the (PA3) sequence of disassembly has been determined in the engine manuals. The employees are guided with the engine manuals due to the high number of components and high standards of the disassembly procedures. However, disassembly in jet engines is not always the reverse of disassembly so that it can potentially cause component damages if using the exact reverse of assembly sequence.

'It's usually engine manual tells you how to do it. In engine manual tells you how to disassemble it. My only real concern is that it is the direct copy of the reverse of the how to build it'

In short, disassembly should be carried out in a specific sequence. Information from the assembly is helpful but not always since the disassembly is not always the reverse of the assembly.

Electronic Maintenance Management Plan (EMMP) provides guidance regarding the level and scope of the work. The level of work determine (PA4) level of disassembly that can be any level between 1 and 3 with fractions between them, i.e. 1.0, 1.1, 1.2...,3.0. Level 1 indicates the lowest level while level 3, which is the highest level, requires the engines to be disassembled into the lowest level. Regarding the level and scope of the works, a manager describes the works as the following:

'When the engine come is, it doesn't mean that you have to do everything said on the [manual] *book. So, we have developed an EMMP and from that we say* ***what level*** *or* ***what scope*** *we're going to do on each module. So, we break the engine down into module and we would say for each one in the module, this is from customer's engine and this is the repair instruction'.*

Degree of (PA5) materials variety in jet engines is relatively low. The material is predominantly titanium alloyed with other material such as nickel and aluminium. For example, the materials for the combustion chamber are nickels and titanium alloys, while the turbine blades consist of titanium and a small amount of aluminium, iron, oxygen and vanadium. The aim of using these materials is to ensure that the engines can resist high temperatures. The alloyed from these materials are used because of their strength, lightweight, and high thermally resistant; these are the essential requirements of the materials for jet engines. Given that the materials have relatively homogenous characteristics (i.e. strength, lightweight, and high thermally), the company does not have much difficulties during disassembly. All the components made from different materials receive similar treatment during disassembly, moving, and handling of the components.

The (PA6) number of components in jet engines can vary from 40,000 - 50,000 depending on the engine type. Because of this high number, the components are classified according to its importance. All critical parts have a serial number on it so that it needs to be rebuilt into the same engine after they have been disassembled. There are also components that require traceability because they are categorised as life limited parts that need for replacements after reaching a certain period of time. Below is the description of how the company copes with higher number of components:

'...each part of that engine, there is a part classification. So if it's a small bolt or nut, it's not interest, there's no serial number on it. If it's a wire or a harness, it's probably gonna no serial number on it. if it's a turbine disk, and that's a life limited part, regulation allows to fly it for 20,000 cycles, then you need a mandatory replacer and you need to have traceability of that part throughout its entire life. So yes, we've got a system that absolutely tract every part's life. That's mandatory requirement to continue their air worthiness'.

The jet engine manufacturers adopt modular design which is part of (PA7) ecodesign principles. However, it is important to stress here that the adoption of modular design is to facilitate manufacturing process due to considerably high number of components in the engine. Nevertheless, the design is still useful for disassembly. With the assistance of the design, the company can disassemble jet engines into different modules that consist of thousand components and inspect the components separately. Some of the modules need to be inspected in more a detailed way while others are less detailed.

There is not any (PA8) smart technology attached in the engines to help the company disassemble the products. There are sensors attached to the engines but the purpose is to provide information and data regarding the performance of the engines. Nevertheless, this is not in the category of smart technology because its usage is to support product information system.

6.5.4. Analysis with existing studies

Table 6.5 aims to highlight the key findings to answer the first research question from narrative description above. Given the first research question has deductive element, the relevant literature related to the findings is presented to compare with empirical evidences.

Table 6.5. Analysis of findings in Company E with existing studies

No.	(CODE) Factors	Result of analysis	Key findings from this case and relevant literature
Organisational characteristics			
1.	(OC1) Degree of the relationship with OEMs	Confirm	Company E, which is part of the OEM, has a more reliable access to cores supply. This finding supports the works explaining that OEMs have better access to obtain cores compared to independent or contract remanufacturers (Lind et al. 2014; Saavedra et al. 2013; Westkamper 2003) and product service system has strongest control over the supply of cores (Östlin et al. 2008).
2.	(OC2) Knowledge transfer from OEMs	Confirm	The company obtains supports from the OEMs particularly regarding original product specifications. Nevertheless, the supports could be useful but some are less relevant as there might be product modifications by customers, extreme operating conditions or accidents during product use (Gungor & Gupta 1998; Tang et al. 2002). Other practices such as managerial decisions, for example production planning and control, are difficult to be adopted from the OEMs (Ilgin & Gupta 2010), and consequently, the company needs to develop by itself.
3.	(OC2) Size of the remanufacturer	Confirm	The findings support the idea of Williams et al. (2001) that small sized companies organise the employees the jobs on a core from start to finish while those in large sized companies, like Company E, adopt job shop system using different employees on each stages. Hence, the findings agree with the existing literature that the company size affects disassembly.
4.	(OC4) Cores sorting	Un-confirm	The company does not organise cores sorting to reject low quality cores as suggested in literature (Tagaras & Zikopoulos 2008; Zikopoulos & Tagaras 2008; Loomba & Nakashima 2012; Galbreth & Blackburn 2006; Sundin & Bras 2005). Due to its high number of components and relatively low volume of cores, the company uses EHMS which function is similar to cores sorting. It seems that cores sorting is only suitable for large number of cores with lower number of components.
5.	(OC5) Product information database	Confirm	Company E utilises product information database in the form of log-book and EHMS. This finding confirms Chung and Wee (2010) who pointed out that the database helps remanufacturers increase profitability through minimising obsolescence, decay and cores damage.

Process choices			
6.	(PC1) Make-to-order versus make-to-stock	Confirm	Company E adopts MTO for its disassembly process and does not hold stocks of disassembled components. Adoption of MTO is possible due to the support of early information collected from EHMS so that uncertainties can be reduced. This finding also confirms previous studies in the way that information can reduce uncertainties which results in reduction in total holding and shortage cost (Ketzenberg et al. 2009; Ketzenberg et al. 2003).
7.	(PC2) Volumes of cores supplies	Confirm	The findings support previous research into this area, which links cores volumes and learning effect of the employees. The high disassembly capacity supplies facilitates employee learning (Jaber & El Saadany 2011) so that disassembly can be carried out more efficiently (Reveliotis 2007).
8.	(PC3) Specific versus general tools and equipment	Confirm	This case study demonstrate that disassembly tasks for jet engines require specialised tools. This finding is in line with the idea from Lee et al. (2010) and Ijomah et al. (2007b) who assert that remanufacturing lack of available tools that can be adopted readily. Complexity of jet engines also increases the need for specialised tools.
9.	(PC4) Generic versus specialised skills	Confirm	Jet engines, which are mechatronic products, require advanced technical and specific knowledge to disassemble. This finding supports the idea of Westkamper (2003) who explains that states complex technical products require specific skills and know-how on about the details of the products, mechatronic components and the optimisation processes.
10.	(NEW) Employee qualification	New factor	There is no study that addresses employee qualification for disassembly in remanufacturing. Existing studies mention that experience accumulated from learning is essential (Reveliotis 2007; Yeh 2012) but no mention is made to specific formal qualifications. Nevertheless, employees in this case company must meet qualifications set up by regulatory bodies in order to be qualified to carry out their jobs.
Product attributes			
11.	(PA1) Value of recovered products	Confirm and extend	The finding confirms the works of Ferrer (2003) and Vadde et al. (2011) stated that remanufacturer has to take into account the estimated yield before carrying out remanufacture. Other similar works are Westkamper et al. (1999) and Subramoniam et al. (2009). The finding also extend the work of Ferguson et al. (2009) who state that remanufacturers reject cores due to their low quality and not feasible economically to remanufacture. In this company, some engine types that have high residual value are not accepted because of difficulties to obtain key components, lack of required skills, capacity constraints or other technical reasons.
12.	(PA2) Functional versus innovative products	Confirm	Products remanufactured in Company E has long life, which a requirement for remanufacturing (Ijomah et al. 2007a). Company E sells the functionality of the products rather that the physical products; this confirms existing literature from which stated that in the new business model companies sell the functionality of capital intensive products (Westkamper 2003). In the new business model, disassembly coupled with assembly play a critical role as these processes determines the length of products' life.

13.	(PA3) Sequence of disassembly	Confirm	The study find that the employees does not need to find the most efficient sequence by themselves since the sequence has been determined in the engines manual. This finding is in agreement with Smith's et al. (2012) who showed that the right sequence reduces time and resources for disassembly. Also, the engines modification made by the airline companies cause changes in disassembly sequence plan (Tang et al. 2002; Gungor & Gupta 1998).
14.	(PA4) Level of disassembly	Confirm	Company E needs to decide optimum disassembly level as it influences the profitability of the remanufacturing. To reduce cost, the company attempts to minimise the strip and additional; the current findings seem to be consistent with Smith and Chen (2011) work who found that full disassembly is not always economically efficient.
15.	(PA5) Types of materials	Confirm	The findings of the current study are consistent with literature reviews carried out by (Go et al. 2011). Most of the jet engine materials are mostly composed of titanium, which have high value, and are durable, strong and lighter than steel. Durability of materials is one of factors that affect product remanufacturability (Ijomah et al. 2007b). The homogeneity makes post-physical disassembly activities easier since almost these materials need similar equipment for handling and moving. Most components require careful treatments.
16.	(PA6) Number of component	Confirm	High number of components in jet engines adds to complexity during disassembly. The evidence supports the idea of Zwolinski and Brissaud (2008) explaining that higher number components leads to a more complicated disassembly sequence that eventually reduce the diassemblability of the products.
17.	(PA7) Ecodesign principles	Unconfirm	Ecodesign is a multi-dimensional concept and modular design is one of it (McGovern & Gupta 2007). The use of modularity in jet engines confirm with a statement from (Ferrer 2001) who argue that design for assembly and disassembly might be coincide. Whilst the purpose of modular design is to help assembly, there is lack of evidence that the design is deliberately intended for disassembly.
18.	(PA8) The use of smart technologies	Unconfirm	This study has been unable to demonstrate the use of smart technologies like active disassembly as suggested by Chiodo and Ijomah (2012), Chiodo et al. (2002) and Ijomah and Chiodo (2010). One of the reasons could be that the development of smart technologies is still in its infancy or this type of products is not well suited for active disassembly. Active disassembly technologies have been implemented in small size products that are remanufactured in mass volumes (Duflou et al. 2006)

6.5.5. Some highlights of the findings

The following is a summary of the qualitative data that is organised into major themes following suggestion of (Maxwell 2005). The following points are the summary of strategies adopted by Company E to manage its disassembly resources so as the disassembly can run smoothly. To achieve this purpose, the company:

- ***Arranges stochastic routes of component flows and does not emphasis on streamlining material flows.*** The purpose is to maximise high value components, not to streamline the material flows. The components have high residual value so that maximizing the reclaimed value is more important than achieving efficiency from streamlining material flows.
- ***Uses handling equipment coupled with careful treatment for the components.*** This is intended to maintain the nature of the components. For example, there is handling equipment that is well suited for each piece of a fan blade. The employees also must wear gloves during the work to avoid fingerprints on the blade. During the handling and moving, the components should also be organised in such a way based on the serial number to support rebuild.
- ***Relies on engine manuals to carry out disassembly that is conducted by qualified employees.*** The employees do not have much room to be flexible since all procedures have been set up. The level of disassembly and which parts should be taken out have been mentioned in the documents.
- ***Uses employees with specialised skills who require formal training, qualifications and experience.*** The company invests a large amount of investment to develop employees with required capabilities. The skills are specific and the positions of employees to carry out jobs are not interchangeable.
- ***Recruits employees who have a formal qualification, trains the employees and requires the employees to attend examination.*** Given that jet engine remanufacturing is a unique industry that has limited numbers of players, employees with these capabilities are extremely difficult to obtain from external recruitment. Also, there is an expired date for the skills and the employees need for recertification to regain the qualification.
- ***Utilises highly specialised and customised design tools and equipment***. The tools and equipment for jet engines are not available in the market and only certain groups possess the tools and equipment to disassemble the products. Combined with employee with specific skills, the use of specialised tools can maximise the value of recovered cores through damage reduction.
- ***Adopts a process oriented factory layout that requires a high investment cost.*** Disassembly operations are carried out in specific areas designated for this purpose only. Different shop floors have different equipment and they are dedicated for different jet engine models.
- ***Disassemble jet engines in units and the models of the engines have been specified.*** The constraint is not only the capacity of the facility but also the model of the engine. This is because different engines require different resources to disassemble. Accordingly, the company has to forecast not only in terms of the number of the production but also the model of the engines and the required resources to disassemble.
- ***Adopts a zero inventory of cores and remanufactured products.*** It would be too costly to keep jet engines in the warehouse before they are remanufactured. Rather than the engines wait in storage for remanufacturing, it would be more beneficial if the engines remain in the airplane and keep the engines flying. Similar case happens to remanufactured engines; the company prefers to dispatch the engines as soon as the engines have been remanufactured.
- ***Relies on forecasting supported with EHMS to develop a robust production schedule.*** The information from EHMS, database and product history provides accurate information regarding to when the engines will return and in what condition.
- ***Can reject to induct the engines and keep the engines flying.*** In this case, the role of EHMS is similar to cores sorting in the way that it functions to sort and obtain early information of the

cores. If the company does not hold 'must have' components or there is lack of expertise to carry out disassembly, they can refuse to accept the engines and keep the engines flying.

- ***Carries out selective disassembly, not full disassembly.*** The scope of the work is determined in advance with work scope definition before the engines arrive at the facility. Once the engines have arrived at the facility, the employee can use bores cope to inspect the components so that the company can minimise the number of works. Not all the components are necessarily taken out.

6.6.Summary of Chapter 6

The objective of this chapter was to analyse the answers for research questions within each individual case as an independent entity. Having identified the answers for research questions within each case company, the next step is to identify the common patterns between cases that will become the final answer for the research questions. This will be discussed in Chapter 7 and 8. Chapter 7 will attempt to analyse the answer for Research Question 1 while chapter 8 will discuss the answer for Research Question 2.

7. FACTORS AFFECTING DISASSEMBLY PROCESS – Empirical Findings

Having analysed each individual case as an independent entity in the previous chapter, the next step is to conduct cross case analysis. By using cross case analysis, the researcher will be able to identify any emerging patterns across cases. It is important to emphasise here that cross case analysis is more than just making a list of 'similarities and differences' between cases (Miles & Huberman 1994) but also to identify the underlying arguments why these patterns emerge (Eisenhardt & Graebner 2007).

Following the suggestion from Yin (2011) for carrying out data analysis, the majority of contents in this chapter is the results from interpreting data and drawing conclusion. Due to the iterative process of the data analysis, during interpreting data and drawing conclusion the researcher should look back at the results from previous steps: compiling, disassembling and reassembling data. The description of the steps is described in Case Study Protocol presented in Appendix III.

To some extent, the research questions establish boundaries and direction regarding the types of analytical tools that are suitable for a study. When undertaking qualitative research particularly, the importance of the analytical tools to be used is even greater, as they will influence the success of the study and be unique for each piece of research; (Miles & Huberman 1994). For these reasons, it is worthwhile restating the research question to be addressed in the present chapter:

RQ1: What are the factors that affect disassembly for remanufacturing?

The general nature of this research is exploratory. However, Research Question 1 also has a deductive element. It attempts to identify the factors affecting disassembly strategies deriving from organisational characteristics, process choices and product attributes. In a deductive study, in order to develop a sound theory, it is necessary to examine existing studies as the foundation for further analysis (Eisenhardt 1989). The constructs that have been identified through the systematic analysis in Chapter 5 will be used to underpin the deductive process in the present chapter. One of the advantages of case study research taking a deductive approach is that it can offer a rich and deep understanding when analysing constructs identified within the literature (Eisenhardt & Graebner 2007).

In Chapter 8, the next stage of this research, the findings of this analysis will be used as the basis for addressing the second research question, which requires an inductive approach. The main factors affecting a disassembly system will be established and used to classify strategies for the disassembly of remanufacturing companies. The use of *a priori* specification of constructs in this research is due to the fact that a 'clean slate' assumption is almost impossible to achieve in theory-building research. The use of existing research as constructs also leads to a more sound theory when the findings confirm those of existing studies (Eisenhardt 1989).

7.1. Empirical findings

In the first instance, factors that have been predicted to affect disassembly strategies, which were presented in Figure 5.1, are analysed using empirical findings to determine whether these sub-factors manifest themselves in empirical findings. As suggested by Eisenhardt (1989), at this stage it is possible that new constructs will emerge. Although constructs identified in the literature review will lead the study in certain directions, the researcher must be flexible in case any new constructs emerge from the case studies. In addition, the use of existing constructs in the new theory is not guaranteed. With this flexible approach, the adoption of a new construct is possible, and thereby will contribute to the originality of the theory (Eisenhardt 1989).

It is important to condense the large amount of data contained within case analysis into more understood data, so that specific patterns can be more easily identified. A failure to condense this data can lead the researcher to unsound conclusions (Miles & Huberman 1994). For this reason, the data from within the case analysis in the previous chapter will be summarised in Table 7.1 to make cross analysis easier. Then, some sort of marking will be undertaken to make comparison between case companies easier. To enable identification whether the factors identified from literature manifest themselves in empirical findings, different markings are used: triple ticks (√√√) represent strong evidence, double ticks (√√) represent moderate evidence, and single tick (√) represents weak evidence. The decision to put triple, double or single ticks is based on the relative strength of the findings across cases. The higher the number of the ticks indicates that the finding in the corresponding case is stronger compared to other cases.

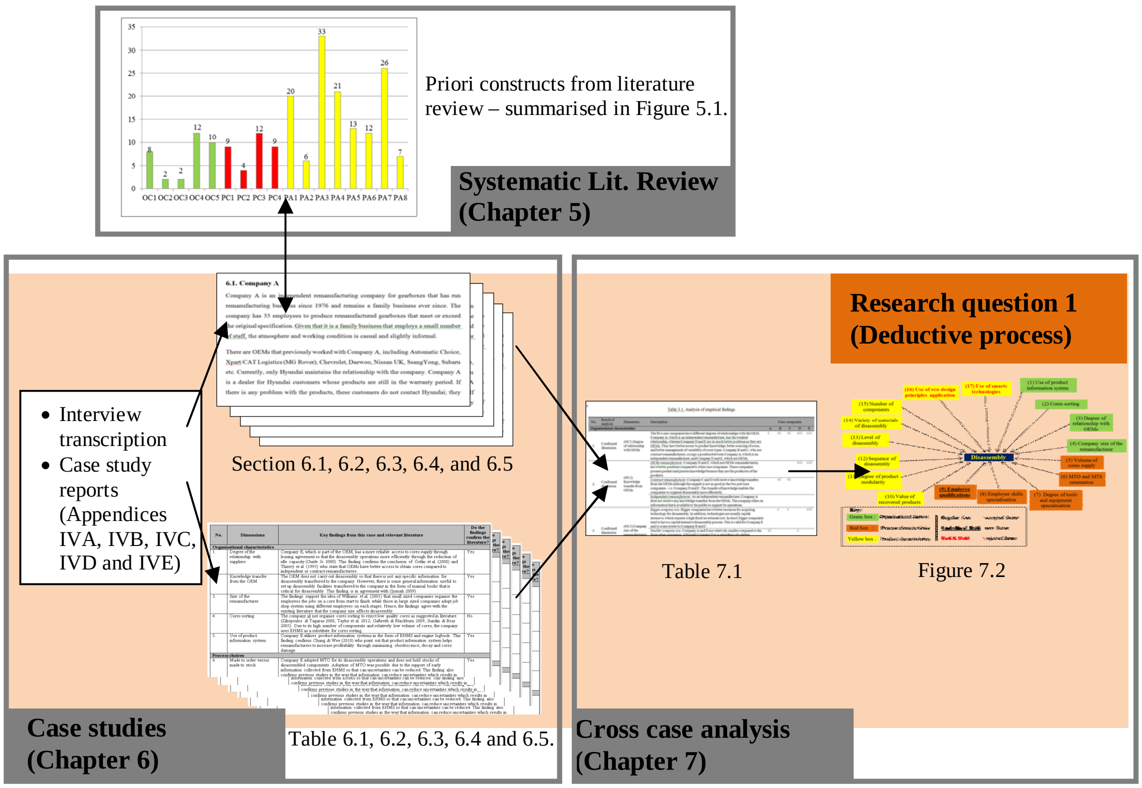


Figure 7.1. Relationship of analysis in Chapter 6 and Chapter 7

At the end of this chapter, a summary of factors affecting disassembly will be presented in Figure 7.2. The graph is developed through a series of stages, started from the findings of the systematic literature review presented in Chapter 5 and combined with empirical analysis in Chapter 6. To review the process of the graph development, Figure 7.1 depicts the relationship between case study reports (Appendices IVA, IVB, IVC, IVD, and IVE), systematic literature review findings (addressed in Chapter 5), key findings from within each case (Tables 6.1, 6.2, 6.3, 6.4 and 6.5 in Chapter 6) and cross case comparisons (to be addressed in the present chapter). The figure shows that the process in this chapter is related to analysis in previous chapters. The relationship between processes also ensures that the output of the analysis has a logical connection.

Table 7.1. Analysis of empirical findings

No.	Result of analysis	(CODE) Factors	Description of the findings	Case company				
Organisational characteristics				A	B	C	D	E
1.	Confirmed	(OC1) Degree of relationship with OEMs	The five case companies have different strength of relationship with the OEMs. Company A, which is an independent remanufacturer, has the weakest relationship, whereas Company D and E are in much better positions as they are OEMs. They have better access to product knowledge, better sourcing of cores, and better management of variability of cores types. Company B and C, who are contract remanufacturers, occupy a position between Company A, which is an independent remanufacturer, and Company D and E, which are OEMs.	√	√√	√√	√√√	√√√
2.	Confirmed	(OC2) Knowledge transfer from OEMs	*OEMs remanufacturer*. Company D and E, which are OEMs remanufacturers, are in better positions compared to other case companies. These companies possess product and process knowledge because they are the producers of the products.				√√√	√√√
			Contract remanufacturer. Company C and D still receive knowledge transfers from the OEMs, although this support is not as strong as for the two previous companies – i.e. Company D and E. The transfer of knowledge enables the companies to organise disassembly process more efficiently.		√√	√√		
			Independent remanufacturer. As an independent remanufacturer, Company A does not receive any knowledge transfer from the OEMs. This company relies on reverse engineering and information that is available to the public.					
3.	Confirmed	(OC3) Company size of the remanufactu rers	*Bigger company size*. Bigger companies have better resources for acquiring technology for disassembly. In addition, technologies are usually capital intensive, which requires a high fixed investment cost. In short, bigger companies tend to have a capital-intensive disassembly process. This is valid for Company E and, to some extent, to Company B and C.		√	√		√√√
			Smaller company size. Company A and D are relatively small, compared to the other three companies. Although Company D is a subsidiary of a global photocopier manufacturing company and offers product-service systems (PSS) to its customers, like Company E, the company itself is a not as big as Company E. Due to the smaller size of Company A and D, the intensity of labour in disassembly process is higher compared to the other cases.	√√			√	

4.	Confirmed	(OC4) Cores sorting	Cores sorting aims to reject low quality cores, and prevent them from entering the remanufacturing facility. The strongest evidence of cores sorting was found in Company B and C. The companies' attempts to increase the homogeneity of cores before the cores enter the disassembly shop floor. As a result, the companies can carry out disassembly with minimum disruption, and material flow on the disassembly shop floor increases. It is possible to carry out this sorting because these companies have a large number of cores stocks. By contrast, Company A, with a lower volume of cores supply, puts less effort into streamlining material flows in disassembly. The company accepts and disassembles most of incoming cores. The company sometimes spends much more time disassembling the cores, but this is not a big issue because maximising the reclaimed value from the cores is more important rather than streamlining material flows in the disassembly shop floor. Company D and E do not organise cores sorting, but they do conduct an activity that is somewhat similar to cores sorting, where they select which product models they are going to disassemble and remanufacture. Company D selects certain photocopier models that are frequently demanded by customers and offer high profitability, while Company E assesses whether the company possesses the resources to conduct the disassembly and remanufacturing for incoming jet engines.		√√√	√√√	√	√
5.	Confirmed	(OC5) Product information database	Company D and E organise a product service system that makes product information easier to obtain. In Company E, real time product information is obtained from the jet engines used by the customers. This information assists the company in minimising uncertainty during disassembly process, through developing more accurate forecasting capabilities and identifying which components should be replaced. A weaker evidence is found in Company D that uses embedded devices in the products that can supply data. However, the data from each device is not either stored or integrated into product information database. The use of product information database to support disassembly process was not found in Company A, B and C.				√	√√√

Process choices								
6.	Confirmed	(PC1) MTS and MTO orientation	*MTO orientation*: The strongest evidence of MTO adoption was found in Company E and B, companies that do not stock finished products. All of the finished products are dispatched to customers. Other case companies adopt MTO but at different levels. Of the five cases, Company A is the weakest adopter of MTO. Company A, which is an SME and independent remanufacturer, undertakes remanufacturing based on direct orders from individual customers, who require customised services and in small volumes. The rest of the work is undertaken in order to build stocks of remanufactured gearboxes, when there are few or no orders from customers.	√√	√√√	√√	√	√√√
			MTS orientation: All case companies adopt MTS, to some extent, except Company B and E. Evidence of MTS adoption can be seen most clearly in Company A. MTS adoption in Company A is due to the fact that there are no orders from customers, and MTS is adopted to eliminate idle capacity. Company D somewhat adopts MTS in order to develop a low level stock, due to the high variety of copy machine models. The stock is limited to popular photocopiers that are in high demand by customers. Company C again slightly adopts MTO as a technique for production levelling.	√√		√	√√	
7.	Confirmed	(PC2) Volume of cores supply	A high volume of cores supplied to the company leads to better techniques in streamlining the material flows on the disassembly shop floor. This was found in Company B and C. To achieve this, the companies sort the cores and carry out disassembly in large batch sizes, so that disruption during disassembly process is minimised. By contrast, where there was a lower volume of cores supply, the company puts less effort into streamlining the material flows in disassembly process. This phenomenon was found in Company A, a small and independent gearbox remanufacturer that receive cores in lower volumes compared to Company B, which is a contract gearbox remanufacturer. It seems that the volume of cores supply does not have high relevance for Company D and E. This is because these companies have capacity constraints in the disassembly facility. In addition, the higher number of components found in photocopiers and jet engines are another reason why streamlining material flows is not a priority for these companies.		√√√	√√√	√	√

8.	Confirmed	(PC3) Specific versus general tools and equipment	*Specific tools and equipment*. This factor is strongly related to the degree of skill specialisation. Employees with highly specialised skills tend to use specialised tools and equipment. Evidence for this was found in Company E. In Company B and C, slightly less specialised equipment is operated by trained and experienced employees. Based on consultation with OEMs, Company B and C developed the customised equipment in-house.		√√	√√		√√√
			General tools and equipment. In Company A and D, most physical disassembly activities are carried out manually, using tools and equipment that can be obtained from market. Due to the generic nature of the tools and equipment, most of them can be used and shared in order to disassemble different product models.	√√			√	
9.	Confirmed	(PC4) Employee skills specialisation	*Employees with specialised skills.* In Company E, there is a hierarchy of skills applicable to different tasks and jobs. The skills needed to perform physical disassembly activities require a sound knowledge of product specification. Employees must attend in-house training or courses with a recommended training provider, pass the exams and gain experience to qualify as disassembly workers. In Company D, employees with a degree in engineering are good candidates to train and develop skills whilst those with the degree and coupled with work experience are more preferred by Company D. The skills developed in Company D are based on product models, not the processes of remanufacturing (e.g. sorting, disassembly, cleaning etc.). Therefore, an employee who can disassemble a product type is not able to disassemble other product types. In Company C and D, training is one of the critical success factors, as the disassembly process uses specialised tools and equipment that are developed in-house. However, rotations are possible to organise because the companies adopt 3-1-3 schemes.		√	√	√√	√√√
			Multi-skilled employees. In Company A, there are six employees allocated to disassembly although other employees can also undertake physical disassembly activities whenever necessary. Job rotation is common in this company so that it becomes responsive and flexible to meet demands from customers.	√√√				

10.	New factor	(NEW) Employee qualifications	No literature mentions any formal qualifications needed to carry out disassembly. Most literature states that disassembly process in remanufacturing is labour intensive, and that no formal qualification is needed. However, Company E, which operates in a highly regulated industry, must comply with regulations from regulatory bodies such as the International Aviation Safety Assessment (IASA) and International Air Transport Association (IATA). Their employees must have certain formal qualifications in order to be eligible for carrying out the jobs.					√√√
Product attributes								
11.	Confirmed	(PA1) Value of recovered products	*High value products*. In Company E, most incoming cores are accepted and disassembled due to their high potential residual value. Company D remanufactures most of the returned cores. The estimated value of cores is based not only on the cores' condition, but also on their potential performance once they have been remanufactured. This is why Company D does not accept certain cores, despite their potential reclaimed value being relatively high.				√	√√√
			Low value products. Conversely, for products with lower potential residual value, the company should assess whether disassembly and remanufacture are economically feasible, or whether buying new is a better option (Company A, B and C). In Company B and C, unless the companies are convinced that the cores offer sufficient potential reclaimed value compared to the remanufacturing cost, the cores are not disassembled. In Company A, most cores are accepted and disassembled. This is due to a lack of cores supply within this company. Sometimes, cores are disassembled but it is too costly to continue the remanufacturing process, and so the cores are rejected in the middle of the remanufacturing process.	√√	√√	√√		
12.	Confirmed	(PA2) Innovative versus functional products	*Less functional products*. Degree of product functionality affects the case companies differently. Company B and C, which are contract remanufacturers, must change their disassembly equipment regularly due to new product introductions from OEMs. Innovative products require constantly changing skills, tools and equipment to be used in disassembly process. The new products can be disassembled using conventional methods, existing skills, tools and equipment, but with the consequence of higher costs. This was found in Company A, which disassembles a large variety of products using the same tools and equipment.	√	√√√	√√√		
			More functional products. Products in Company D and E have a considerable long life cycle, a feature that is typical of functional products. The companies sell the functionality of the products under leasing agreements. In Company				√√	√√

			D, innovation affects investment in people skills. Company D must expend both time and financial resources in order to train its employees so they can adapt to the new products released by OEMs. Similarly, this also affects people skills, qualifications of employees and equipment for Company E, which must train its employees in order meet the requirements of regulatory bodies if the company is receiving new product models. However, the frequency of the required training in Company E is much lower than that in Company B and C because the former company remanufactures less innovative products than the latter.					
13.	Confirmed	(PA3) Sequence of disassembly	*More rigid sequence of disassembly.* Broadly speaking, the simpler the structure of the products, the more alternative sequences there are available to disassemble them. Where products are simple, physical disassembly activities can be carried out using different sequences without causing damage; however, for products with complex structures, an identification of the relationship among components is required prior to physical disassembly activities to ensure that no damage will be caused. Consequently, complex structures require more time to identify the most optimum sequence, as well as to set up and prepare the facility before physical disassembly activities can be carried out. This situation was found in Company D and E.				√√√	√√√
			Less rigid sequence of disassembly. Compared to jet engines and photocopiers, gearboxes and automotive engines have a more flexible sequence of disassembly. This is because the precedence relationship is simpler. Company A and B disassemble the same products (i.e. gearboxes), but their methods of disassembly are different. In Company A, no specific guidance is provided regarding the sequence of disassembly, although in Company B the sequence has been determined as part of the remanufacturing production line. In Company C, a predetermined sequence is used for disassembling automotive engines.	√√√	√√	√√		
14.	Confirmed	(PA4) Level of disassembly	*Full disassembly.* Different product types require different levels of disassembly. Decisions on how to determine the level of disassembly for these products are also different. Of the five cases, Company A, B and C carry out full disassembly.	√√√	√√√	√√√		
			Partial disassembly. Jet engines and photocopiers are partially disassembled, but the final decision regarding the level of disassembly is different for the two products. The jet engines require a case-by-case approach contingent on various factors, such as the condition of the engines, the location of the problem and the quality of cores. Having been disassembled in the first stage, the modules and components are assessed further to see whether a higher level				√√√	√√√

			of disassembly is necessary. This process is iterative in nature and repeated several times. Partial disassembly is carried out in order to minimise the amount of work required, which will also reduce costs. On the other hand, photocopiers require more standardised decisions, set up by the company. The level of disassembly for photocopiers is known in advance. Many modules can be disassembled but some of them cannot. If the company insists on disassembling them, they are broken and cannot be remanufactured.					
15.	Confirmed	(PA5) Type of materials	*More heterogeneous materials.* The main materials used in photocopiers (Company D) are metals, plastics and glasses. These different types of materials require different treatment in the post-physical disassembly activities, particularly regarding handling and moving, as certain components are very sensitive and will not tolerate scratches, even minor ones. The variety of the materials also increases the complexity of handling and moving after the physical disassembly activities. Similarly, jet engines (Company E), which are made from magnesium, require specific treatment during both the physical disassembly activities and post-physical disassembly activities. In this case, the post-disassembly activities refer to the handling and movement of components because materials made of magnesium has high value and the precisions of the components should be maintained.				√√	√√√
			More homogenous materials. The materials used in automotive components (Company A, B and C) are quite homogenous, except some minor components such as rings that are made from rubber. These components are allowed to be damaged during disassembly as they will be replaced with new ones.	√√√	√√√	√√√		
16.	Confirmed	(PA6) Number of components	*Higher number of components.* Number of components affects disassembly level and post-physical disassembly activities. For jet engines (Company E), which consist of a very high number of components and have a complex product structure, disassembly is carried out partially to minimise cost. The jet engines also require customised design equipment to move and handle disassembled components. The effect of number of components on disassembly level is also found in photocopier but with weaker evidence than that in jet engines.				√√	√√√
			Low and medium number of components. In terms of the number of components, automotive engines (Company C) and gearboxes (Company A and B) have fewer than photocopiers (Company D) and jet engines (Company E). Although Company A, B and C undertake full disassembly, the methods of	√√	√√	√		

			performing it are not identical due to the difference in number of components. Company C, whose products have a higher number of components, use a more structured approach compared to Company A and B. The risk of damage in products with a higher number of components is higher due to wrong sequences being used in physical disassembly activities.					
17.	Unconfirmed	(PA7) Eco-design principles	All respondents agree that the adoption of ecodesign principles make physical disassembly activities. It appears that there is some indication of ecodesign principles found in the disassembled cores. However, there is no clear evidence regarding whether the principles are deliberately applied with the purpose of assisting product recovery and, in particular, physical disassembly activities. For example, the managers of Company A and D admitted that more recent product models of photocopiers are easier to disassemble. The manager of Company E also expressed a similar view. However, he is uncertain about adoption because the application of ecodesign could coincide with the interests of manufacturers. The parent company of Company E, the jet engine manufacturer, uses modular design to build their products. The design not only helps the company manufacture the product, but also provides benefits during disassembly process. Clearer evidences are found in Company B and C, whose managers stated that there are no or very little attention given to eco-design during the product design stage.					
18.	Unconfirmed	(PA8) Smart technologies	A smart technology that has been used in practices is shape memory alloys, but there is no evidence of using such technology to assist disassembly in the case companies. This technology offers ease of disassembly of complex products in a cost-conscious way. It appears that none of the respondents are aware of such technology.					

Key:
√√√ : strong evidence in the case company
√√ : moderate evidence in the case company
√ : weak evidence in the case company

7.2. Discussion

This chapter aimed to identify the factors affecting disassembly for remanufacturing, taking a deductive approach to the analysis of constructs identified within the literature, and supported by empirical evidence from the field. Generally speaking, the empirical evidence is consistent with the findings of the existing studies that are discussed in the literature review. Of the 8 factors proposed in the product attributes category, 6 are confirmed, whilst 2 others are not confirmed. Factors relating to product attributes seems to be more dominant, in comparison to factors from other categories, such as organisational characteristics and process choices. The factors affecting disassembly process are depicted graphically in Figure 7.2.

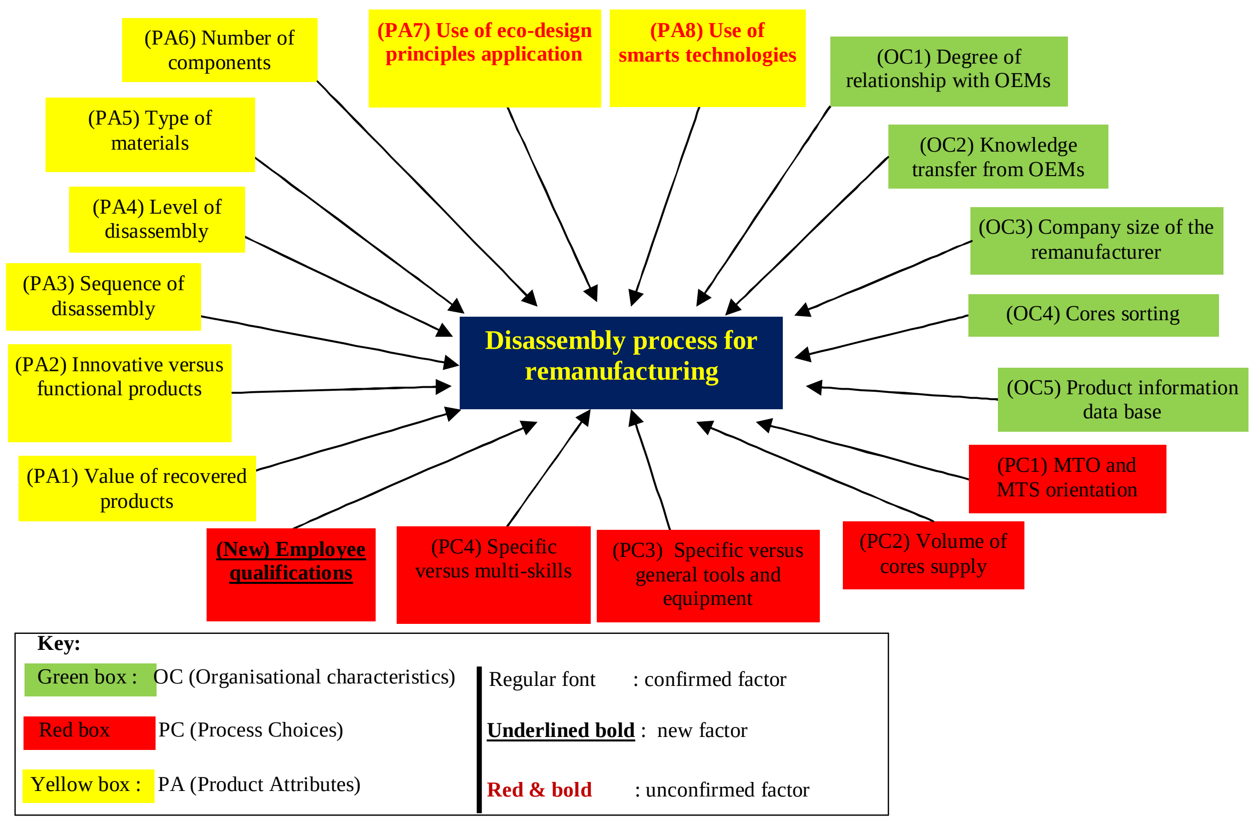


Figure 7.2. Summary of empirical findings

Based on the analysis of this chapter, there is no contradiction in the direction of the relationship between disassembly and the factors affecting it, which indicates its consistency. An example of a contradictory finding is that the number of components had a negative effect on disassembly in one case company, but it was found to have a positive effect in other case companies. However, all case studies consistently support the idea identified in the literature that a higher number of components requires a more complex disassembly process.

Some of the factors are not confirmed across all case companies, for example the use of a product information database and core sorting. However, this does not mean that these factors should be excluded from further analysis. Use of a product information database to support disassembly is only found in Company E, while other companies who decide not to use the database admit that it could be beneficial but it is not necessary at the present time. Therefore, the findings of this study show that there is no conflicting opinion regarding the advantages of a product information database, even though the practices of the companies are, at present, different. Based on this finding, it is evident that there is no conflicting opinion regarding the benefit of product information database to support disassembly. Thus, this factor, which is confirmed in one case company, but not all cases, should still be considered to be confirmed.

A further interesting observation is that the analysis identified some anomalies, unique findings that occur only occasionally. An example of this regards so-called ‘classic’ products, which are considered somewhat differently, as the residual economic value of the classic products remanufactured by Company A is unusually high. This is unusual because, theoretically, the greater a product’s age, the lower its residual value. However, components of classic products, for example those made in the 1960s-1970s, have an extremely high value, as they become rare, and are not readily available on the market. This is relevant when considering Company A, which disassembles and remanufactures components regardless of their year of production. In cases such as this, the decision to disassemble is based on whether or not the company has the capability and resources to remanufacture these types of products.

Job specialisation can be arranged for different processes in remanufacturing, or for different product models. Products that have a high number of components and complex structures require a higher level of specialisation. For example, jet engines require higher specialisation as compared to photocopiers. Job specialisations for jet engines are organised according to processes and product models. On the other hand, job specialisation for the remanufacturing of photocopiers is organised based on product models only. This finding implies that products with a high number of components and complex structures require greater investment in non-physical infrastructures, such as training and human resource development.

7.3. Summary of Chapter 7

This chapter dealt with the analysis of empirical findings against constructs that have been prepared from the systematic literature review. The constructs consisted of factors affecting disassembly derived from organisational characteristics, process choices and product attributes. Of the 17 factors identified from the literature review, 15 were confirmed. In addition, a new factor emerged from empirical findings so that the final result of the list of factors affecting disassembly is 16. The fact that the majority of the constructs were confirmed indicates that the findings from empirical investigation corroborate existing studies.

The next chapter will elaborate how case companies develop disassembly strategies based on the factors that have been identified in this chapter. To do this, there are several steps that should be followed until the purpose of developing disassembly strategy framework is achieved. This will be discussed in more detail in the next chapter.

8. DEVELOPMENT OF A DISASSEMBLY STRATEGY FRAMEWORK – Cross-case analysis

This chapter is aimed at discussing the second research question. Like the first one, which was analysed in Chapter 7, to answer the second research question the researcher has conducted a cross-case analysis to identify emerging patterns across the different cases. Similar to the previous chapter, the content of this chapter predominantly is the results from interpreting data and drawing conclusion (see Appendix III). A brief review of the second research question is as follow:

RQ2. How do remanufacturing companies manage disassembly based on the factors affecting it?

Given that RQ2 is inductive in nature, the researcher used an exploratory approach to identify common patterns amongst the case companies to develop a new theory. One of the prerequisites that a theory emerges from empirical findings is that there are constructs found in each case, which are confirmed across all the cases and supported with logical arguments that explain how they are interrelated. Equally important is the need to avoid different interpretations of the collected data. The key strategy to cope with this challenge is to present the data in an objective way so that all readers has the same understanding (Eisenhardt & Graebner 2007).

8.1. The steps of the analysis

In this chapter, the researcher attempts to find general patterns across the cases and discover how underlying logical arguments explain the patterns. To achieve this, the researcher analysed the results from within-case analysis discussed in Chapter 6 and compared the case findings against the proposed research questions. To answer Research Question 2, the researcher used Sections 6.1.5, 6.2.5, 6.3.5, 6.4.5 and 6.5.5 that were developed from within-case analysis, as discussed in Chapter 6. The steps which are undertaken to answer Research Question 2 are presented in blue colour in Figure 8.1.

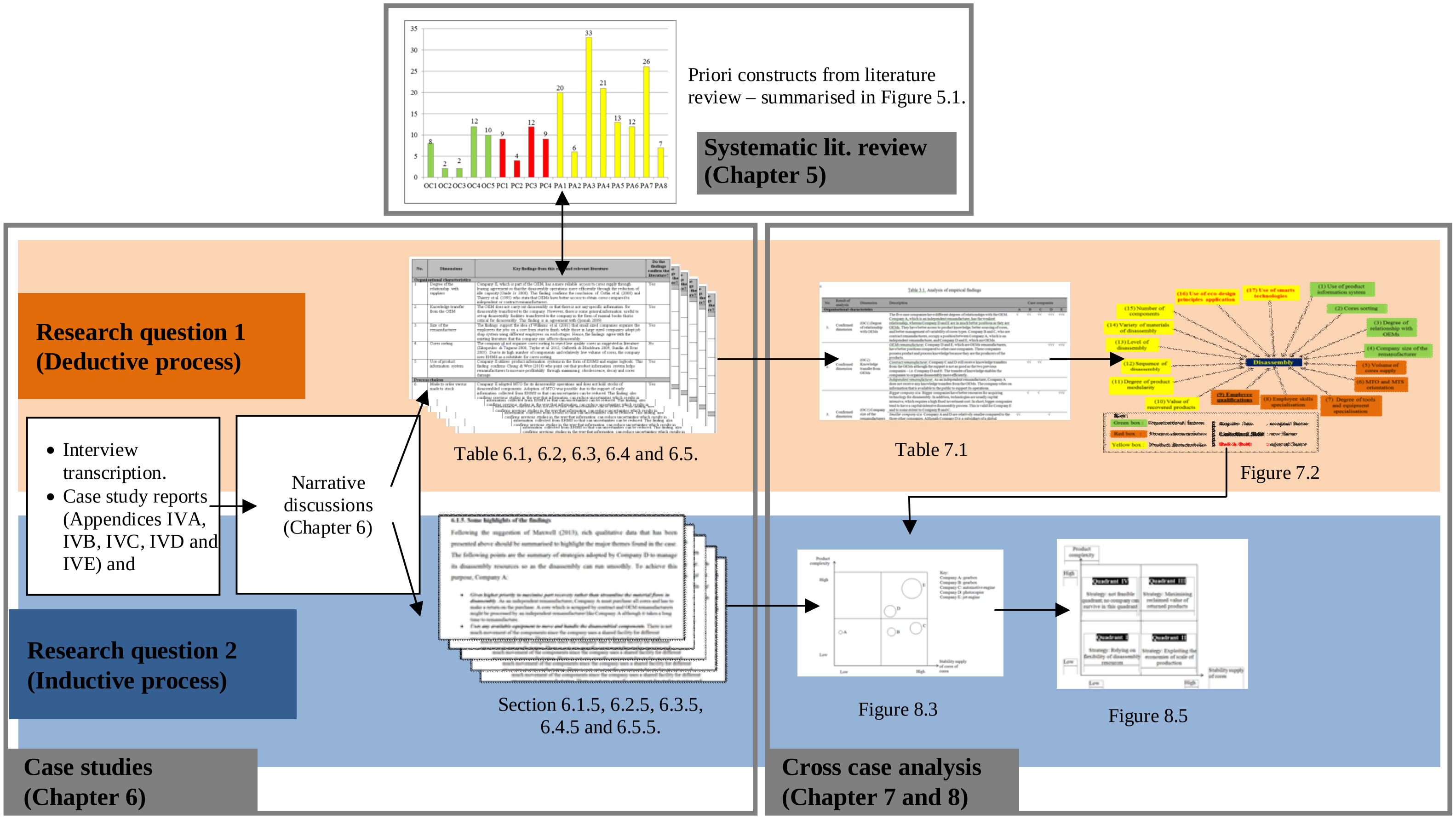


Figure 8.1. Steps of analysis to answer Research Question 2

8.2. Grouping of the factors affecting disassembly process

As we have seen in Chapter 7, there are a considerably high number of factors that have been identified from empirical evidence. In fact, a total of 17 factors were identified from the findings.

Due to the reasonably high number of factors that were identified from the analysis in previous chapters, it is difficult to consider them individually during this analysis. Grouping them, based on their relationship, is necessary to simplify how the overall factors affect disassembly. The factors that refer to the same construct are all grouped into one category. The grouping of the constructs is important to ensure that they are conceptually interrelated (Eisenhardt & Graebner 2007). After this categorisation, there are eleven factors in the product complexity category, while the stability of cores supply consists of five factors (Figure 8.2).

The researcher decided to categorise the factors, as mentioned in the preceding paragraph, for two main reasons. First, it is difficult to develop a framework of disassembly strategies that is based on a large number of factors used in the analysis. Moreover, an analysis that uses each individual factor separately will not result in comprehensive conclusions. Second, empirical findings demonstrated that none of the case companies confirmed all the factors that were identified from literature review, and therefore, comparing the factors one by one will not produce a satisfactory result. So, categorising a number of factors into two factors – i.e. product complexity and stability of cores supply – will allow the researcher to carry out a more realistic analysis.

Table 8.1 and Table 8.2 present the logical relationships of how each dimension and the main factors (i.e. product complexity and the stability of cores supply) are interrelated. To emphasise the argument of how each dimension is related to the main factors, the phrases that are related to the main dimensions in the cells are written in ***bold and italic.***

Table 8.1. Grouping of factors into stability of cores supply

No.	(CODE) Factors	Relationship with stability of cores supply	
		Positive	Negative
1.	(OC1) Degree of the relationship with the OEMs	Both Company D and E are OEMs. Their status as OEMs, which are combined with leasing agreements, results in the strongest relationship with customers, which eventually leads to a more ***stable supply of cores***. Contract relationships, which were found in Company B and C, come next. Contract relationships offer advantages to the stable supply of cores as well, but to a lesser degree. The relationships ensure that remanufacturers always have a supply of cores from OEMs.	Company A, which is an independent remanufacturer, does not have permanent core suppliers and this has a negative effect on the ***stability of cores supply***.
2.	(OC2) Company size of the remanufacturer	A bigger company typically has more automated processes, so that a more ***stable supply of cores*** is needed to avoid the high cost of idle capacity. In the mean time, a smaller company does not have automated process, but rather flexible disassembly process. This was found in Company A, which is the smallest company and has the least stable cores supply.	
3.	(OC4) Cores sorting	Core sorting is related to the stable supply of cores, for both the disassembly shop floor and overall remanufacturing operations. Company B and C, which receive a more ***stable supply of cores***, prefer to arrange sorting to avoid low quality cores being disassembled. As a result of this sorting, the cores that arrive in the disassembly facility are more standardised and, consequently, the cores flow more smoothly compared to those without sorting.	
4.	(PC1) MTO versus MTS	MTS can be used to reduce idle capacity due to fluctuating demand from customers and a low ***stability of cores supply***. To overcome this low ***stability of cores supply***, Company C remanufacture cores that are available in the inventory as part of a production levelling strategy.	Companies adopting MTO are more likely to have a fluctuating supply of cores, due to uncertainty about orders from customers. The evidence is most apparent in Company A, whose production is mainl MTO and whose orders come from individual customers.
5.	(PC2) Volume of cores supply	A high volume of cores supply can be used for production levelling, so that cores that arrive at the disassembly facility are distributed more evenly. Some of the excess cores can be used as stocks and will be used later when the company has a low supply of cores. Both Company A and C adopt this production levelling method. So, high volume of cores supply can be used to increase stability of cores supply to disassembly facility.	

Table 8.2. Grouping of factors into product complexity

No.	(CODE) Factors	Relationship with product complexity	
		Positive	Negative
1.	(OC2) Knowledge transfer from OEMs	***Products with high complexity*** are more difficult to disassemble, when there is no support from OEMs that possess product knowledge. For this reason, complex products are disassembled and remanufactured in house by OEMs. Company E is a good example of this phenomenon.	
2.	(OC5) Product information database	A product information database could be used to support parts explosion that happens during the physical disassembly activities of products with a high numbers of components. The higher the number of components, the higher the need for the database because more complex products typically have a higher number of components. The use of a database to support the remanufacturing ***of complex products*** was found in Company E.	
3.	(PC3) Multi-purpose versus specialised tools and equipment	Specific tools and equipment are needed to ***disassemble complex*** products. The use of inappropriate tools can potentially cause damage, and reduce the potential reclaimed value. The most apparent evidence for this was found in Company E and to some extent company C and D.	In Company A, multi-skilled employees use multi-purpose tools and equipment to disassemble cores with a less ***complex product*** structure. The employees use the tools and equipment for different product types. Multi-purpose tools and equipment do not function properly in complex products that require specific tooling.
4.	(PC4) Specific versus multi-skilled employees	***Complex products*** demand a higher qualification of skills and knowledge to disassemble. In complex products, various components in different sizes, shapes and materials require different tools to disassemble. The tools and equipment require specific skills to operate. The most apparent evidence for this phenomenon was found in Company E.	
5.	(PC5) Value of recovered products	***Products with a high complexity*** require expensive advanced manufacturing processes. At the end of their life, these products still contain a high recovery value. As a result, although the products have been used, the remaining value is still considerably high. The strongest evidence for this phenomenon was found in Company E while the rest of the companies provide support with weaker evidence.	

continued

No.	(CODE) Factors	Relationship with product complexity	
		Positive	Negative
6.	(PA1) Innovative versus functional products	Unique serial numbers in jet engines add to ***complexity of products***. The components have to be reassembled into the same engines that create more complex process during remanufacturing.	Functional products tend to have more standardised components that do not have a unique serial numbers, which reduces ***product complexity***. Gearboxes remanufactured in Company A and B are all functional products and the components are interchangeable.
7.	(PA2) Sequence of disassembly	***Products with high complexity*** need a more well planned disassembly sequence. This planning is intended to identify the most efficient sequence that will minimise the time and resources spent on disassembly. The sequence of disassembly for jet engines in Company E is guided by engine manuals to find the optimum sequence.	***Less complex products*** can be disassembled in a number of flexible ways. This is because there are more alternative disassembly sequences for products with less complex structures. This was found in Company A, which disassembles gearboxes in many different sequences.
8.	(PA3) Level of disassembly	There is a higher tendency to select partial disassembly, rather than full disassembly, when the products have a ***high complexity***. Jet engines in Company E, for example, are not disassembled completely but they undergo partial disassembly only. As a substitute of not undertaking complete disassembly, the products undergo a series of tests to ensure that the non-disassembled components meet the expected criteria. The decision to carry out partial disassembly is intended to reduce the amount of works and minimise costs.	Less ***complex products*** are fully disassembled without a deep economic consideration. Gearboxes, which are remanufactured in Company A and B, are disassembled completely to ensure that every component meets the criteria of remanufactured products. The cost to disassemble the products is not an issue because it is not high.
9.	(PA4) Type of materials	The heterogeneity of the materials adds to the ***complexity of products***. The variety of the materials makes the moving and handling of components more difficult. Products in Company D are made of a number of materials. During the physical disassembly activities and post-physical disassembly activities, the components made of different materials should be treated differently so that damage can be avoided.	Homogenous materials reduce ***product complexity*** and make the disassembly process much easier. In Company A, B and C, whose products are mostly iron based, disassembly is much easier. All the components are treated equally without any specific requirement, such as using specialised tools and equipment for handling and moving.

continued

No.	(CODE) Factors	Relationship with product complexity	
		Positive	Negative
10.	(PA5) Number of components	The number of components is one of the factors that affects ***product complexity***. A high number of components results in more complex decisions during disassembly process, including what sequence will be used is, what the level of disassembly is, and what tools are required for physical disassembly activities. Company E presents apparent support for this argument.	
11.	(NEW) Employee qualification	Due to the high ***complexity of the products***, regulations and industry standards, employees working in Company E need a formal qualification to carry out remanufacturing. These three factors are related with one another. Typically, the higher the complexity, the higher the qualification that is required to carry out the jobs.	

The factors affecting disassembly have been categorised into two main factors – i.e. product complexity and the stability of cores supply – which is depicted in Figure 8.2. To summarise the factors affecting disassembly, the researcher utilises different techniques, including narrative analysis, which is presented in the tables (Table 8.2. and Table 8.3) and a graph (Figure 8.2), since the combination is more comprehensive than using either one of them alone (Miles and Huberman 1994).

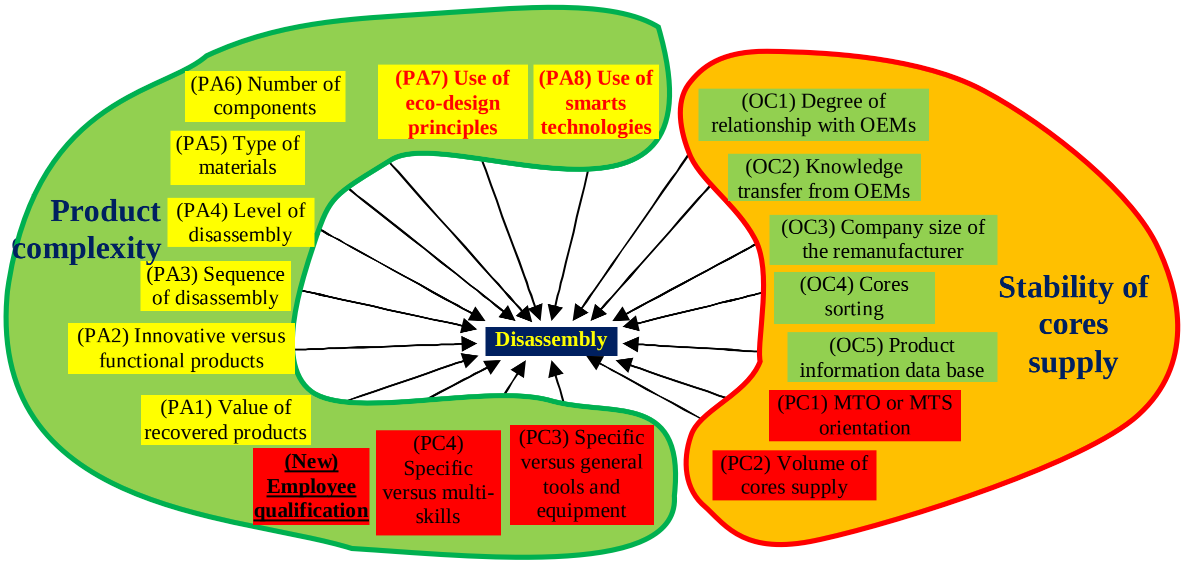


Figure 8.2. Classification of factors affecting disassembly

As mentioned above, the factors are classified to form two main factors that can summarise all of the corresponding factors. The most appropriate concept that can summarise the 9 factors (i.e. specific versus general tools and equipment, specific versus multi-skills, employee qualification, value of recovered products, innovative versus functional products, sequence of disassembly, level of disassembly, type of materials, and number of components) is product complexity. Product complexity has been cited in as multidimensional concepts and all the 9 factors represent the all dimensions that compose product complexity.

On the other hand, the 7 factors refer to another concept. These all 7 factors (i.e. degree of relationship with OEMs, knowledge transfer from OEMs, company size of the remanufacturer, cores sorting, product information data base, MTO or MTS orientation, and volume of cores supply) converge into a single concept what so called as stability of cores supply. Stability supply of cores is selected as the title of the concept because it is a multidimensional concept that can summarise all the 7 factors.

Having discussed how the factors are related and why the factors are classified into two main groups, the researcher used the two factors to determine the position of the company in the framework. The positions of the case companies in the disassembly framework are depicted in Figure 8.3.

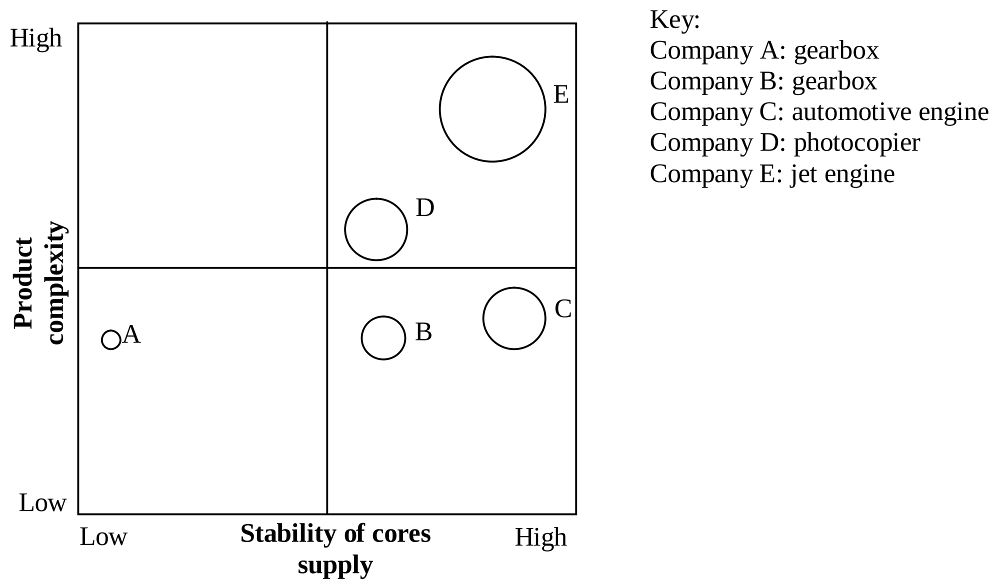


Figure 8.3. Position of the companies in the classification of strategies

8.3. Analysis of strategies

To identify the strategies adopted by different case companies, a cross-case analysis of the findings obtained from Chapter 6, Sections 6.1.5, 6.2.5, 6.3.5, 6.4.5 and 6.5.5, would be used. Having been collated, the overall strategies from different companies are presented in Table 8.4. Presentation in a single table is intended to make the comparison between the case companies easier.

Table 8.3. Grouping of strategies

Techni-ques and methods	Quadrant I	Quadrant II		Quadrant III		Quadrant IV
	To manage disassembly process, Company A...	**To manage disassembly process, Company B...**	**To manage disassembly process, Company C...**	**To manage disassembly process, Company D...**	**To manage disassembly process, Company E...**	
Strategies on materials flows	***A1. Gives higher priority to maximise part recovery rather than streamline the material flows in disassembly.*** As an independent remanufacturer, Company A purchase stock of cores and has to make a return on the purchase. A core which is scrapped by contract and OEM remanufacturers might be processed by an independent remanufacturer like Company A although it takes a long time to remanufacture.	***B1. Stabilises the volume of production over time.*** The company attempts to maintain volume of production at a constant rate. A large number of cores coming from diversified customers ascertain that the company never lacks demand and supply of cores.	***C1. Minimises idle capacity due to high volume of production.*** The company utilises production levelling to distribute production evenly across different periods. Reducing idle capacity is important since the company spends a large amount of fixed cost investment to set up the facility.	***D1. Attempts to maximise reclaimed value of cores.*** Streamlining material flows is less important than optimising the value of recovered components. The reason to maximise reclaimed value is that the components have a high residual value.	***E1. Arranges stochastic routes of component flows and does not emphasis on streamlining material flows.*** The purpose is to maximise high value components, not to streamline the material flows. The components have high residual value so that maximizing the reclaimed value is more important than achieving efficiency from streamlining material flows.	
Tools for moving and handling process	***A2. Uses any available equipment to move and handle the disassembled components.*** There is not any specific equipment devoted to moving and handling the disassembled components; and if available, the equipment is also used for other purposes.	***B2.*** Different gearbox models use different crates to carry the components during the post-physical disassembly activities. The crates are designed specifically for different product models. All of this equipment is intended to minimise the risk of damaged components and streamline the component flows.	***C2. Classifies the components based on their families.*** The components need similar processes are categorised in the same group and moved together afterwards. The purpose of this is to minimise cost of movement.	***D2. Classifies the components based on the characteristics and uses separate equipment to handle and move them.*** Photocopiers are made of different materials that have a different nature. In addition, there are many components that are small in size and are sensitive, for example, sensors that are small in size and fragile. These components should be handled and moved separately from others.	***E2. Uses handling equipment coupled with careful treatment for the components.*** This is intended to maintain the nature of the components. For example, there is handling equipment that is well suited for each piece of a fan blade. The employees also must wear gloves during the work to avoid fingerprints on the blade. During the handling and moving, the components should also be organised in such a way based on the serial number to support rebuild.	
Formalisa-tion of disassembly procedures	***A3. Carries out full disassembly and the sequence has not been determined in advance.*** There is not any formal document that provides guidance on how to disassemble. The employees disassemble the cores based on their preference and experience. Due to this unformalised procedure, there is a big variation between cores in terms of disassembly time and cost.	***B3. Develops strict procedures to disassemble.*** Employees disassemblecores and then put disassembled parts into the customised designed crates in a very short time, because they are supported by a manual guidance. All these steps have been prepared by a research team. The employees are familiar with where each piece of the component should be placed in the crate.	***C3. Develops a formal procedure to carry out full disassembly supported with documents.*** Although automotive engines can be disassembled in different sequences, the company formal procedures that should be followed by the employees. This technique results in efficient disassembly time.	***D3. Determines a general sequence under which disassembly should be carried out.*** In addition to this, there is a specific sequence for different models of photocopiers. Both the generic and specific sequence should be followed so that all the components can be recovered easily during the rebuild process.	***E3. Relies on engine manuals to carry out disassembly that is conducted by qualified employees.*** The employees do not have much room to be flexible since all procedures have been set up. The level of disassembly and which parts should be taken out have been mentioned in the documents.	
Resource sharing – Human resource	***A4. Organises job rotation frequently since there is not any job specialisation.*** This is because the employees have multi-skills and the task to disassembly does not need specific formal requirements. There is no regulatory body that requires employees to have certain qualification to conduct disassembly.	***B4. Equip employees with specialised skills.*** The employees are organised using 3-1-3 schemes to allow job specialisation. In this scheme, there is an employee skill matrix that can map who can do what. Employees can do 3 jobs, in which they have the expertises, but not all jobs.	***C4. Develops employee skills matrix to allow job rotations.*** Company C adopts a 3-1-3 scheme for employee skills so that the employees have specialised skills but still can be rotated in some ways. The job rotation allows the company to better allocate the employees while some degree of specialised skills enable them to work more efficiently.	***D4. Conducts employees rotation but at a limited opportunity.*** Employee transfers are possible between different processes in remanufacturing but the transfer is not possible between different photocopier models.	***E4. Uses employees with specialised skills who require formal training, qualifications and experience.*** The company invests a large amount of investment to develop employees with required capabilities. The skills are specific and the positions of employees to carry out jobs are not interchangeable.	

Continued

Employee skills development and qualification	***A5. Uses informal training through peer-by-peer coaching.*** The training is informal in nature and not structured. More experienced employees provide the training to less experience employees during daily operations.	***B5. Trains the employees to gain product knowledge and to use the specialised tools and equipment.*** Employees do not necessarily have formal qualification but they have to attend an in-house training developed by R&D team.	***C5. Provides training to new employees.*** Before the employees are eligible to carry out the disassembly task, they have to undergo formal training, then work to serve somebody, do the same job alongside somebody else, do the job but under supervision of a more senior employee, and finally become eligible to perform the job independently.	***D5. Employs disassembly operators that have relevant formal qualifications, relevant work experience and mechanical aptitude***. Not all employees in the company are eligible to hold the position as a disassembly worker. A good candidate should have a degree in engineering, relevant work experience that deals with machinery and a good mechanical aptitude.	***E5. Recruits employees who have a formal qualification, trains the employees and requires the employees to attend examination.*** Given that jet engine remanufacturing is a unique industry that has limited numbers of players, employees with these capabilities are extremely difficult to obtain from external recruitment. Also, there is an expired date for the skills and the employees need for recertification to regain the qualification.	
Resource sharing – tools and equipment	***A6. Uses multi-purpose equipment available in the market.*** All cores regardless of the type, models, or year of production are disassembled at the same facility. This strategy allows resource sharing between different product models and reduces fixed cost investment.	***B6. Designs the factory much like a production line that uses specific tools to disassemble and customised equipment for handling disassembled parts.*** The cores flow in the line from one shop floor to another. Once the cores have been disassembled and the components have been put in the customised crates, they are moved to other shop floors using this line.	***B6. Utilises some customised design tools and equipment that are operated by skilled employees***. The customised tools and equipment are used to meet the specific purpose of disassembly tasks. To operate the tools and equipment, the employees are trained so that they can do the disassembly tasks in a very efficient way.	***D6. Utilised general tools to disassemble***. Tools and equipment are readily available in the market so that the company does not need to develop customised tools.	***E6. Utilises highly specialised and customised design tools and equipment***. The tools and equipment for jet engines are not available in the market and only certain groups possess the tools and equipment to disassemble the products. Combined with employee with specific skills, the use of specialised tools can maximise the value of recovered cores through damage reduction.	
Investment policy to set up facilities	***A7. Spends low fixed cost facility and uses multi-purpose equipment.*** All cores are disassembled at the same facility cores regardless of the type, models, or year of production. The facility is used to disassemble cores with different models, manufacturers and year of production.	***B7. Spends high investment to set up customised physical infrastructure such as tools, equipment and disassembly shop floor.*** Tools and equipment that are used to disassemble require customised designs for different gearboxes types. For example, the company spends approximately as much as 3,000 pounds for each type of gearbox. This cost is spread over 5 years.	***B7. Spends high investment to set up dedicated disassembly shop floor.*** The investment covers spending to develop tools in-house, employee training, and develop formal procedures for disassembly. The factory organises its facility using a cellular design and a dedicated shop floor for disassembly.	***D7. Sets up a facility to maximise the value recaptured from the cores***. The facility includes equipment to interrogate the machine electronically, training for the employee, update the skills of the employees to disassemble, and recruit the best available people to occupy the position.	***E7. Adopts a process oriented factory layout that requires a high investment cost.*** Disassembly operations are carried out in specific areas designated for this purpose only. Different shop floors have different equipment and they are dedicated for different jet engine models.	
Volume of production	***A8. Runs production in low volumes and serves niche market.*** Most of the orders are in small volumes because the orders come from retail customers who demand customised services. For these customers, the company charges premium prices. On many occasions, the company does not receive any orders from customers so that the company processes the cores from the stock to reduce idle capacity.	***B8. Uses high volume lot sizes***. This is because the company adopts some sort of line production system to serve orders from industrial customers (OEMs). Production in high volume lot sizes is preferred rather than in units to reduce fixed cost.	***C8. Disassembles in large batch and high production volume***. This strategy aims to minimise the fixed cost coming from investment in the infrastructure such as building customised tools, equipment, and training for the employees. To achieve this purpose, the company is supported with contractual agreement from OEMs as cores suppliers, a large number of cores stocks to ensure the availability of raw materials and production levelling.	***D8. Disassembles in units, not in batches or lots.*** There are good demands for remanufactured products and all of the products are sold easily to market. If there is an employee on holiday, there will be a significant reduction on production volume. This is because one employee works on a core from start to finish and each employee could remanufacture different photocopier models.	***E8. Disassemble jet engines in units and the models of the engines have been specified.*** The constraint is not only the capacity of the facility but also the model of the engine. This is because different engines require different resources to disassemble. Accordingly, the company has to forecast not only in terms of the number of the production but also the model of the engines and the required resources to disassemble.	
Inventory management	***A9. Builds a considerable high amount of stocks cores and remanufactured products.*** The stocks are used to reduce idle capacity in case there are not any orders from customers. Periodically, the stocks are dumped or sold to other parties at considerably low prices once they reach a certain level.	***B9. Stocks a large number of cores. The cores arrive to the facility daily from different customers so that the company never lack of cores supplies.*** There is no stock of remanufactured products because they are always dispatched to the customers once the remanufacturing has been completed.	***C9. Maintains stock of cores at a certain level during the contract periods.*** Finished products will be dispatched as soon as they have been completed. Stocks are available at almost every stage of remanufacturing process as part of production levelling strategy.	***D9. Attempts to adopt a zero inventory for remanufactured products.*** The company can obtain cores very easily so that stocks of cores are built as anticipation of unexpected demands. The company needs to anticipate what photocopiers model that will be demanded because there is a wide variety of models.	***E9. Adopts a zero inventory of cores and remanufactured products.*** It would be too costly to keep jet engines in the warehouse before they are remanufactured. Rather than the engines wait in storage for remanufacturing, it would be more beneficial if the engines remain in the airplane and keep the engines flying. Similar case happens to remanufactured engines; the company prefers to dispatch the engines as soon as the engines have been remanufactured.	

Continued

Production schedule and forecasting	***A10. Adopts a flexible production schedule.*** This is due to uncertain orders from retail customers in the market. Employees who carry out disassembly are multi-skilled workers that can be rotated with other positions.	***B10. Adopts a robust production schedule.*** This is intended to streamline the flow so that the disassembly runs smoothly and efficiently. To make disassembly run quicker, typical problems in gearboxes have been identified so that during disassembly some components that cause problems and cannot be used again can be disassembled destructively.	***C10. Carries out forecasting to develop robust production planning and scheduling***. This strategy is used to minimise idle capacity and enable the disassembly shop floor to operate in an efficient way. The company organises joint forecasts with the customers to develop production planning so that inefficiency due to time uncertainty can be minimised.	***D10. Relies on historical data to forecast what models the customers usually request.*** A small deviation on the production forecast can cause a large amount of cost spent. The production planning is mostly developed based on historical data and the company disassembles the cores in units rather than in batches.	***E10. Relies on forecasting supported with EHMS to develop a robust production schedule.*** The information from EHMS, database and product history provides accurate information regarding to when the engines will return and in what condition.	
Gate keeping of incoming cores	***A11 Does not organise sorting and most of incoming cores are accepted.*** The company accepts cores in any condition because the employees are flexible to disassemble any product models with a large variety of quality condition. The company tolerates problems during disassembly such as longer time to disassemble and high resources spending to disassemble caused by the variance in cores condition.	***B11. Conducts cores sorting***. This is intended to reject low quality cores to enter the disassembly shop floor. After the cores have been sorted, the cores quality becomes more homogenous. Low quality cores can cause some disruption and makes disassembly longer than normal, whereas quick disassembly is the main purpose that the company attempts to achieve.	***C11. Organises cores sorting***. The company attempts to avoid low quality cores from entering the disassembly facility since it may cause disruption during disassembly. For example, rusty nuts and bolts may become sticky and difficult to separate. This can cause some disruption on the flow of disassembly on the shop floor.	***D11. Disassemble cores that are suitable to be remanufactured***. Type of the photocopiers that will cause problems during the leasing period can be predicted. All cores can be disassembled and remanufactured but the company only selects the most profitable cores for remanufacturing. For cores that are not suitable for remanufacturing, the company disassembles them and retrieves certain components for cannibalisation.	***E11. Can reject to induct the engines and keep the engines flying***. In this case, the role of EHMS is similar to cores sorting in the way that it functions to sort and obtain early information of the cores. If the company does not hold 'must have' components or there is lack of expertise to carry out disassembly, they can refuse to accept the engines and keep the engines flying.	
Level of disassembly	***A12. Decides to disassemble all cores completely without a depth analysis.*** When disassembly is underway, sometimes the company just realises that it is too costly so the disassembly is discontinued.	***B12. Disassemble completely all cores that have been sorted.*** Cores that have been sorted are disassembled completely in a fast and efficient way. Disassembly can be carried out efficiently because the cores are relatively homogenous after they have been sorted.	***C12. Carries out full disassembly***. During disassembly sometimes there are some components that have to be disassembled destructively. The full disassembly is needed to make other processes in remanufacturing possible.	***D12. Undertakes disassembly into the level under which the cores can be remanufactured***. The cores are not disassembled completely since some of the modules will be broken if they are disassembled completely.	***E12. Carries out selective disassembly, not full disassembly.*** The scope of the work is determined in advance with work scope definition before the engines arrive at the facility. Once the engines have arrived at the facility, the employee can use bores cope to inspect the components so that the company can minimise the number of works. Not all the components are necessarily taken out.	

The key strategies from Table 8.4 are summarised and presented in Figure 8.4. For quadrants that have more than one company on them, the strategies of the companies are combined, as presented in the figure. The letters and numbers within parentheses indicate the codes of the case studies, while the frequency of the appearances of the codes shows the strength of the evidence.

Complexity of cores (Low → High)	Low ← Stability of cores supply → High	
High	**Quadrant IV** **(High product complexity, low stability of cores supply)**	**Quadrant III** **(High product complexity, high stability of cores supply)**
	None of the case company is in this quadrant; it is very risky for any company to stay in this quadrant and might not be able to survive due to the lack of economic feasibility.	1. Prioritise to recover high value components (D1; E1E1E1) 2. Utilise specialised tools and equipment (D6D6; E6E6E6) 3. Employ workers with specialised skills (D5; E5E5E5). 4. Adopt a robust production schedule – a small deviation results in high cost (D10D10D10; E10E10) 5. Disassemble cores in low volume (D8D8D8; E8E8E8) 6. Accept or reject decision based on products model (D11D11D11; E11E11E11) 7. Use rigid procedures to disassemble (D3; E3E3E3). 8. Conduct partial and selective disassembly (D12;E12E12E12)
	Quadrant I **(Low product complexity, low stability of cores supply)**	**Quadrant II** **(Low product complexity, high stability of cores supply)**
Low	1. Serves niche markets and charges premium prices to customers (A8A8A8) 2. Prioritises parts recovery rather than streamlining material flows (A1A1A1) and accepts cores in any condition (A11A11A11) 3. Carries out full disassembly (A12A12A12) 4. Lack of formalisation in disassembly procedures (A3A3) 5. Implements flexible production schedules (A5A5A5) 6. Employs operators with multi-skills (A4A4A4) who use multi-purpose tools (A6A6A6) 7. Use buffer stocks to reduce idle capacity (A9A9A9).	1. Equips employees with specialised skills (B4B4B4; C4C4) 2. Disassembles in large volumes (B8B8B8; C8C8) 3. Adopts robust production schedules-- small deviation results in high effect (B10B10B10 C10C10) 4. Organise sorting to reject low quality cores (B11B11B11; C11C11C11) 5. Adopts a standardised process using specialised tools and equipment (B2 B2 B2; C2C2) 6. Spends high cost investment to set up facility (B7B7; C7C7C7). 7. Formalises and standardises disassembly operations (B3B3B3; C3C3)

Low **Stability of cores supply** High

Key:
L: letter, indicates the code of the case companies; N: number, indicates the number of strategies in Table 8.3
LN : weak evidence found in the case
LNLN : moderate evidence found in the case
LNLNLN : strong evidence found in the case

Figure 8.4. Summary of the strategies in different quadrants

8.4. Development of framework of disassembly strategies

Remanufacturing companies that choose different compositions of the disassembly strategies are mentioned above. Different compositions result in different output of the strategy. Companies positioned in the same quadrant adopt the same or similar composition of strategies, which creates an identical output of disassembly strategy.

The following section discusses how the case companies develop their disassembly strategies. The focus of the discussion is only the issues that are under the control of the case companies. Some issues are inherent and remanufacturers are not able to control them. Product design, for example, is not under the control of the contract or independent remanufacturers. Manufacturers have determined the product design so the case companies do not have the ability to change it. In the discussion below, the keywords of the strategies that have been adopted by the case companies, which are presented in the Figure 8.4, are written in *italic* and are followed with the code of the companies and the number of strategies.

8.4.1. Quadrant I: Low product complexity, low stability of cores supply

In general, case company that occupies this quadrant serves *niche markets* (A8) and charges the customers from the market with *premium prices* (A8). The company can charge a price to customers well above the average market price due to its customised services and unique services that it can offer. To support serving a niche market, the remanufacturer utilises flexible human resources with *multi-skills* (A4) that work with *multi-purpose tools and equipment* (A6). The company has to be flexible to adjust to a wide variety of customer demands and uncertain production schedules. The cores are *disassembled completely (A12)* without any supporting documents that specify in what sequence and which components should be disassembled. The use of multi-purpose tools and equipment operated by multi-skilled workers is possible because the workers have accumulated skills from a long period of time. They are also able to work without supporting documents because of their unique skills to disassemble a wide range of products. This is the knowledge that cannot be obtained in other companies because it has to be developed by the company itself (Lind et al. 2014).

The company accepts cores of any condition, so that it *does not need to organise sorting* (A11). This is common for remanufacturers that do not have a stable supply of cores, or if they have to buy the cores from other parties. For this reason, the company has to *optimise cores recovery (A1)* to offset the expense of obtaining cores. On some occasions, the disassembly process has to be discontinued just after the company realises that the cores are not economically feasible to remanufacture.

This condition leads to the operation of the company being more costly. Another reason for costly operation is that idle capacity frequently that occurs due to a lack of cores. To reduce idle capacity, the company in this quadrant adopts a *flexible production schedule* (A5) and develops a high level of *buffer stocks of cores* (A9), which also results in high inventory holding costs. As a result, the company has to optimise between high inventory holding cost of cores and the idle capacity from uncertain demands. However, all of these costly operations have been compensated by premium prices charged to customers.

The case company located in this quadrant has to bear high variably costs due to a fluctuating production schedule, unstandardised processing time, idle capacity, a small batch production volume and a high variety of products. Typically, these characteristics belong to small and medium-sized enterprises, like company A. From the discussion in the two paragraphs above, it is clear that the main strategy is the ***flexibility of disassembly resources***. This flexibility is needed in order to adapt to a low volume of production, as well as an uncertain type of products and conditions.

The main strategy of case companies located in Quadrant 1 is to utilise the flexibility of the disassembly resources, including employees, tools and equipment.

8.4.2. Quadrant II: High stability of cores supply and low product complexity

High production capacity can reduce fixed cost and increase efficiency. Remanufacturers in this quadrant run high volume productions using standardised processes; this strategy is possible due to stability of cores supplies, which arrive in large volumes and thus offer remanufacturers economies of scale in the production process.

In order to reap the benefits of large-scale production, companies in this quadrant make *a large investment* (B7C7) into *building customised tools and equipment* (B2C2) in-house, with the assistance from OEMs. To run disassembly facilities supported by these customised design tools and equipment, the companies employ *workers with specialised skills* (B4C4). The combination of customised tools and equipment as well as specialised skills means that companies are able to carry out *disassembly in large volumes* (B8C8) and using more *standardised processes* (B3C3). The result is that disassembly can be carried out more efficiently, although companies must *invest a lot of money to set up the facility* (B7C7).

To reduce the variety of cores that arrive at the disassembly facility, companies *organise cores sorting* (B11C11). This rejects low quality cores and prevents them from entering the disassembly facility, and is possible where companies have a large supply of cores. These cores may require longer processing times or cause disruption during disassembly; in addition, low quality cores typically do not have a high residual value. Therefore, the benefit of recovering low quality cores is often unlikely to offset the cost of recovering them.

The procedures involved in the disassembly process have been standardised and formalised to *support robust production schedules* (DB7C7). A small deviation in the schedule can result in a high cost for the overall remanufacturing operations; this is due to the fact that companies operate in high volumes to achieve economies of scale. Thus, a small deviation causes either over-stock or stock-out of remanufactured products.

Remanufacturers in this quadrant are able to disassemble a large number of cores because the production volume is a function of the tools, equipment and skills of the employees. Evidence for this finding is more apparent in Company B than Company C, as the former disassemble more complex cores than the latter. With the support of specialised tools and equipment developed in-house, companies in this quadrant can *disassemble a large volume of cores* (B2C2).

In short, companies in this quadrant organise some sort of production line, similar to those in the manufacturing system. The system disassembles a large number of products by using customised equipment, which requires a high investment cost to set up. In summary, companies occupying this quadrant are ***exploiting the economies of scale of production***.

The main strategy of case companies located in Quadrant 2 is to exploit the economies of scale of production.

8.4.3. Quadrant III: High stability of cores supply and high product complexity

Companies in this quadrant attempt to *maximise the recovery of the high residual value* (D1E1) from complex products. The high value of the products is resulted from a complex structure, expensive materials and an advanced method of product manufacturing processes. The products that consist of a large number of components and high technology contents require *specialised skills* (D5E5) *and equipment to disassemble* (D6E6). These skills are needed to ensure that the remanufacturers can avoid damage to components during the disassembly process. Employees are not easily transferred between shop floors, as they have specialised skills that enable them to operate customised tools and equipment, which are organised with a cellular design layout. Companies in this quadrant require employees to not only have formal qualifications, but also to attend trainings. In short, employee qualifications in this quadrant are higher than those in Quadrant II.

Given that the remanufacturers in this quadrant need employees with specific skills, tools and equipment, not all of the cores can be disassembled in the companies. For this reason, the remanufacturers in this quadrant can decide to *accept or reject the cores* (D11E11) before they arrive at the facility. The cores are therefore not accepted or rejected due to their low quality, but because the models do not suit the company's capabilities.

Company E develops a *robust production schedules* (D10E10) with the support from information technologies and a reliable market forecast. In Company E, the engine health management system provides a forecast of when the engines will arrive and in what condition. Similarly, closed-loop supply chain managed by Company D enable it to forecast with high accuracy when and what type of products that will be needed by customers. Leasing agreements with the customers, which are mostly industrial customers, make this effort easier.

Having a demand forecast is critical here because the remanufacturers in this quadrant disassemble in *low production volume* (D8E8). A small deviation in the demand forecast can result in the companies experiencing idle capacity. Company E disassembled and remanufactured roughly 370 engines in 2012, while Company D remanufactures approximately 40 per month. These figures are much lower in comparison to companies that are located in Quadrant II. The complexity of products hinders the capacity of companies in Quadrant III to disassemble a large number of cores.

Remanufacturers in this quadrant are different from companies in other quadrants because they *undertake selective and partial disassembly* (D12E12) to reduce cost, rather than always carrying out full disassembly. Besides, selective and partial disassembly also reduces the risk of damaged components, so that the reclaimed value can be maximised. This is possible to do because the products are equipped with EHMS and electronic devices that provide information about the condition of the cores and which parts need to be replaced. In summary, companies that occupy this quadrant are attempting ***to maximise the reclaimed value of their returned products.***

The main strategy of case companies located in Quadrant 3 is to maximise the reclaimed value of their returned products.

8.4.4. Quadrant IV: Low stability of cores supply and high product complexity

None of the case companies are located in this quadrant because it is lack of economic feasibility. High product complexity requires a large investment to set up a facility and that causes many problems for companies located in this quadrant. This means it will be very difficult for them to survive due to the high cost of operations. It is very risky for any company to stay in this quadrant as they might not be able to survive due to the lack of economic feasibility. This quadrant is identical to the companies that are located outside the diagonal of the product-process matrix (Hayes and Wheelwright 1979).

However, it is still possible for existing remanufacturers from other quadrants to expand slightly and serve the market in Quadrant IV. Given that remanufacturing is an after-market business, the nature of this business tends to be entrepreneurial, in which the players are seeking opportunities. Where business opportunities exist, there will always be business players emerging. A more detailed analysis regarding how remanufacturers attempt to expand to other quadrants will be discussed in the next section. The condition of Quadrant IV can be summarised as follow:

None of the case companies are in this quadrant. It is very risky for any company to stay in this quadrant and they might not be able to survive due to the lack of economic feasibility.

8.4.5. Summary of strategies in different quadrants

A summary of strategies that are adopted by the case companies located in different quadrants is presented in Figure 8.5.

There are differences and commonalities of techniques that are utilised by the case companies located in different quadrants. For example, Quadrants I and III are located on the diagonal left-bottom and top-right respectively, and companies located in these quadrants have some contradicting strategies. Companies located in the former quadrant use general equipment and multi-skilled workers, while those in the latter utilise employees with specific expertise who are working with equipment that is designed for a specific purpose.

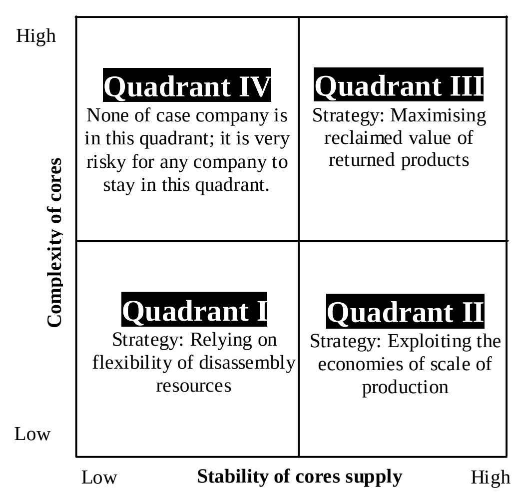


Figure 8.5. Summary of disassembly strategy framework

On the other hand, some commonalities are found. Remanufacturers located in Quadrants II and III share some methods as they have a high stable supply of cores. Companies in these quadrants adopt robust production planning and schedules that are designed to minimise idle capacity. Companies located in Quadrants I and II also have some methods in common because they have a low level of product complexity that enables full disassembly. A low level of product complexity permits the companies to perform full disassembly without requiring a depth analysis.

Despite differences in the methods and techniques adopted by companies from different quadrants, this does not imply that the adoption of certain disassembly strategies neglects other strategies. For example, the company in Quadrant I that focuses on the flexibility of disassembly resources does not, as a result, neglect cost reduction. The company located in Quadrant I still takes cost minimisation into consideration, but the focus is still flexibility, as that is more important than minimising the cost of disassembly. On the other hand, there is still some effort to develop flexibility in Quadrant II, but it is not as high as in Quadrant I.

There is some variation in the strategies of the companies in the same quadrants. Nevertheless, the variation is not a contradicting pattern, but rather it indicates differences in the strength of the findings. For example, both Companies D and E, which are located in Quadrant III, remanufacture complex products, but the level of product complexity is different. Jet engines are more complex than photocopiers because the former has more components than the latter. The technology embedded in photocopiers and jet engines is also different. Photocopiers consist of optical, mechanical and electrical technologies, while jet engines require mechanical and electrical as well as advanced manufacturing methods to build them. Due to these differences, jet engines require higher level of employee skills and more specialised tools and equipment.

The case companies adopt the best possible option for their current operations. It is possible that companies can move from a quadrant to another quadrant to keep their positions remain optimum. For example, Company C used to be an independent remanufacturing company and its position was in Quadrant I. Then, the company signed contractual agreements with OEMs. Following the signing of the contract, the position of the company moves from Quadrant I into Quadrant II. This is due to the fact that the stability of cores supply increases after the company sign contracts with OEMs.

The generalisability of the framework is valid for most products and remanufacturing companies that have similar or the same characteristics. In terms of products, remanufacturing is only suitable for certain product types and most of the relevant products have been included in this study. As an example, automotive products have been mentioned as the most popular products in remanufacturing industry and they are also included as the objects of analysis in this study. This study also covered all type of remanufacturing companies (i.e. OEM, contract and independent remanufacturers) and different types of relationship with cores suppliers (e.g. deposit based, product service system, stock-based, service based agreement, etc.). In short, the generalisability of this study can cover a wide range of products that are suitable for remanufacturing and various types of remanufacturing companies.

8.5. Discussion on the disassembly strategies

Having discussed how remanufacturers located in the different quadrants adopt different strategies, this section elaborates on how remanufacturers in a certain quadrant attempt to expand to other quadrants. Any potential consequences and obstacles of the expansion will be discussed because companies from different quadrants will experience different challenges and advantages when they expand to the other quadrants.

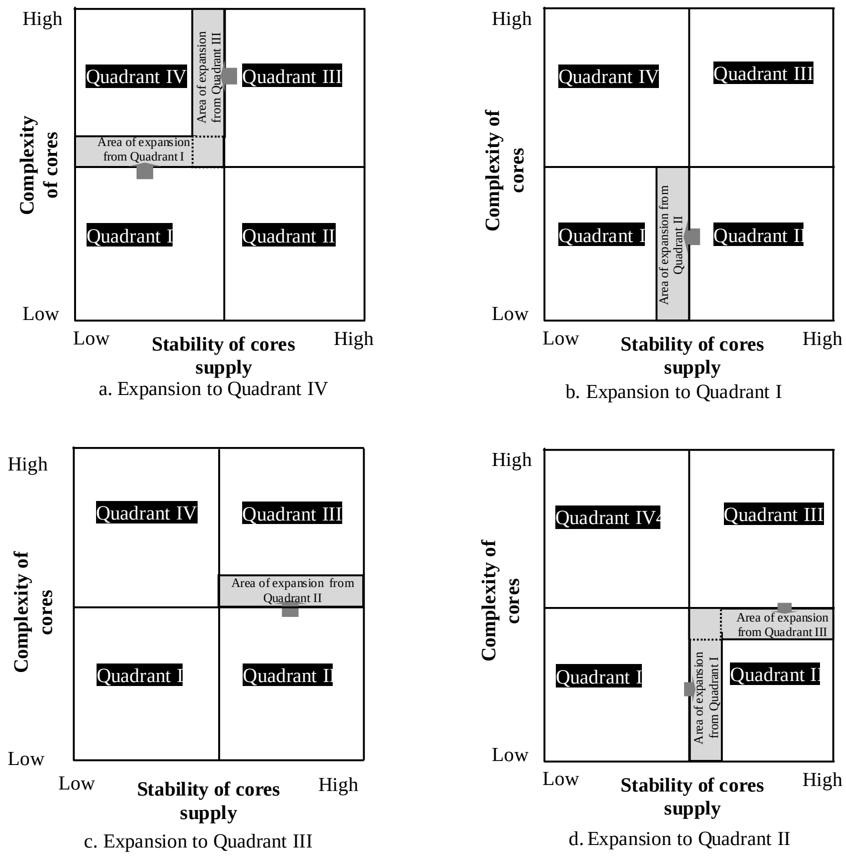


Figure 8.6. Expansion of remanufacturers to other quadrants

8.5.1. Expansion of Quadrant I and III to Quadrant IV

As we have discussed in previous sections, Quadrant IV refers to an economically unfeasible quadrant, so there is no way that any company can survive in the quadrant. However, it is possible for remanufacturers that are located in other quadrants to slightly expand to this quadrant (Figure 8.6.a). Due to the entrepreneurial nature of the remanufacturing business, it seems that this quadrant is only a side job for the remanufacturers located in Quadrants I and III. The most likely market players that will expand into Quadrant IV are remanufacturers located in Quadrants I and III.

Remanufacturers in Quadrant I will face challenges when they want to expand slightly into Quadrant IV. The companies have to spend some additional investment because complex products require more capital-intensive resources. Alternatively, the companies could use their existing resources, which would result in a less efficient disassembly process, with longer disassembly times, higher defect rates and higher amount of human resource allocation. Companies from Quadrant I, which are typically small-sized independent remanufacturers, have the advantage of a good experience when they serve the after-market, so they have a better understanding of how to capture the market's needs (Seitz & Peattie 2004).

Potential candidates that could expand into Quadrant IV are the companies located in Quadrant III because they have capabilities to disassemble products with a high complexity. The main obstacle for companies to expand into Quadrant IV is that they are not flexible enough. Remanufacturers located in Quadrant III are big companies that are associated with OEMs that have a mass production mentality (Subramoniam et al. 2009). The characteristic of an uncertain supply of cores found in Quadrant IV is not well suited with the attitude of OEMs. As a result, although remanufacturers in Quadrant III have the capabilities to take the opportunities that are available in Quadrant IV, it is less likely that they will do that.

8.5.2. Expansion of Quadrant II into Quadrant I and III

Remanufacturers occupying Quadrant II can expand into Quadrant I (Figure 8.6.b). The companies have a higher production capacity and the same level of product knowledge that is required for Quadrant I. The main question is whether the products that are offered in Quadrant I are economically feasible, since the supply of the cores is not constantly available. A more challenging situation is found when remanufacturers from Quadrant II attempts to expand into Quadrant III (Figure 8.6.c). Quadrant III that remanufactures high value complex products are typically suitable for in-house remanufacturing (Martin et al. 2010; Guide & Van Wassenhove 2003). The findings of this study confirm that statement. High product complexity creates various costs if the OEMs intend to outsource their remanufacturing activities, such as the cost to select contract remanufacturers, expenditure for coordination between product design and design process, as well as the expense of testing and remanufacturing.

In addition, OEM remanufacturers attempts to create obstacles for independent remanufacturers to enter the business (Sundin et al. 2012). When it comes to products with high complexity, OEMs hesitate to share their product knowledge, remanufacturing know-how and other relevant information to other parties. As the information has high economic value, OEMs prefer to remanufacture in-house. Therefore, to expand into Quadrant III the key issue are how to obtain the cores and acquire expertise about the products.

8.5.3. Expansion of Quadrant I and III into Quadrant II

Remanufacturers that occupy either Quadrants I or III can expand into Quadrant II (Figure 8.6.d). Companies in Quadrant I are typical players in the remanufacturing industry; they are small, independent and privately-owned remanufacturers (Guide Jr. 2000). These companies have the advantage of disassembling products with similar characteristics to that of Quadrant IV, i.e. low product complexity. The only adjustment that they have to make is to stabilise production schedules, as they currently operate in a flexible environment. In short, there is not any significant challenge for remanufacturers from Quadrant I. They even gain an advantage from expanding to Quadrant I to II because the supply of cores is the main problem for independent remanufacturers (Geyer & Jackson 2004; Lind et al. 2014). The advantage of this expansion is the reduction of idle capacity due to a more stabilised production schedule.

Remanufacturers in Quadrant III experience challenges in expanding to Quadrant II. They used to remanufacture complex products with a typically high residual value. The skilled employees would be overqualified, and the tools and equipment and other facilities would be too advanced to disassemble products with a low complexity. In addition, the employees and other disassembly resources have to adjust to the high volume of productions, which have a low profit margin. In short, even if the expansion is possible to do, it is unlikely that remanufacturers in Quadrant IV would be interested in doing this.

8.6. Validation of disassembly strategy framework

8.6.1. Method: Review by a panel of experts

In the field of operations management, one of serious concerns regarding the outputs of research is lack of industrial relevance (Platts 1993). Platts explains how research in the field is typically of little relevance to industry. To address this issue, the findings of this study were validated through a review conducted by a panel of experts. Validation using a panel of experts has been used in previous research across a wide range of disciplines, for example to validate tools for risk assessment (Soon et al. 2012), criteria for clinical supervision (Hyrkäs et al. 2003), criteria for assessing the behaviour of patients (Hsu et al. 2014) and software process improvement models (Beecham et al. 2005).

To gather the opinions of the panel of experts, the researcher organised interviews and a group discussion which was preceded by a short presentation that explained an overview of research topic. The responses to these interview and group discussion are important, since they provide explanations as to *why* respondents give certain answers. It is these answers to *why* that provides a true *understanding* of participant responses (Meredith 1998). The responses to the validation instrument were combined with interview and narrative answers from the questionnaire; they were analysed qualitatively, and no statistical test was used.

8.6.2. Members of the expert panel

There were 3 academia and 4 practitioners in the field of remanufacturing selected as members of panel. The experts were selected due to their extensive knowledge regarding the practices of disassembly in various remanufacturing companies, and so that they are able to assess the positions of companies in different quadrants.

Another method to assess the generalisability of findings is using a new case as suggested by Meredith (1998). However, this study used expert opinions, rather than using a case company, for several reasons. First, the experts who were selected have extensive experiences, and have visited or worked in more than one remanufacturing company. Accordingly, the assessment of each expert can represent more than one company, and more than one quadrant in the framework. Second, the use of a case company most likely can only validate one quadrant – i.e. the quadrant in which the company is located in the framework of disassembly strategy. Third, the positions of experts are independent from the remanufacturing companies and, consequently, they can carry out objective reviews regarding whether the strategies of remanufacturers located in different quadrants of the proposed framework are valid.

Table 8.4. Criteria for assessing research validity

Criteria	Definition (Thomas & Tymon 1982)	No.	Questions to respondents
Descriptive relevance	*'The accuracy of research findings in capturing phenomena encountered by the practitioner in his or her organizational setting'.*	1	The framework closely represents real practice in remanufacturing companies.
		6	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.
		11	*The framework above does not represent disassembly strategies to any great extent.*
Goal relevance	*'The correspondence of outcome (or dependent) variable in a theory to the things the practitioner wishes to influence'.*	2	Disassembly strategies presented in the framework above are important for remanufacturing companies.
		7	*Not understanding the disassembly strategy framework above may cause remanufacturing companies adopt the wrong strategies.*
		12	The disassembly strategies presented in the framework are useful in some way.
Operational validity	*'The ability of the practitioner to implement action implications of a theory by manipulating its causal (or independent) variables'.*	3	The disassembly strategy framework can be implemented in real practice.
		8	*I find the framework above is difficult to follow.*
		13	The framework can be used to help remanufacturers improve disassembly.
Non-obvious-ness	*'The degree to which a theory meets or exceeds the complexity of common sense theory already used by practitioner'.*	4	The framework helps me to understand the various strategies for carrying out disassembly processes.
		9	*There are many major issues missing from the framework.*
		14	The framework above looks like it has potential to help managers make better decisions.
Timelines	*'The requirement that a theory be available to practitioners in time to use it to deal with problems'.*	*5*	*The framework is not useful for remanufacturing companies in organising present operations.*
		10	The disassembly strategy framework described above is an important area to address.
		15	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.

Source: the definitions are adopted from Thomas and Tymon (1982) while questions are adapted from Ijomah (2008) and Errington (2009)
*No. refers to the number that was used in the instrument for validation (see Appendix V)

8.6.3. Criteria for validation

The validation instrument utilised in this research uses the five properties of research relevance developed by Thomas & Tymon (1982), which have been widely accepted for use in the operations management field. Although the properties were proposed more than three decades ago, they are not outdated. In remanufacturing research specifically, they have been recently used by Ridley (2013) and Errington (2009). To increase consistency, there were 3 questions to test each property. Sentences written in italics are negative statements of other questions, and are intended to check the consistency of respondents' answers. In the instrument distributed to respondents, the sequence of questions presented in Table 8.4 was randomised so that increases the objectivity of answers from the experts. The result of validation is presented in Table 8.5.

8.6.4. Results of validation

8.6.4.1. Descriptive relevance

The responses for questions to assess descriptive relevance predominantly meet expectation. The answers for Questions 1 and 6 were predominantly 'agree' and 'strongly agree' which demonstrate high descriptive relevance of the framework. Slightly different results were found for Question 11 that used negative statement. The researcher expected that the experts would answer 'slightly disagree' to 'strongly disagree' to this negative sentence. However, the responses for this question were mixed between 'agree' and 'disagree'. Two of the experts responded 'strongly agree' with this negative sentence that was used in the question.

The responses from two experts above contradict to what they stated in the meeting. During the meeting, all the experts agree that the framework is real representation of disassembly strategies in remanufacturing companies. Thus, the responses in the questionnaire contradict to what they have stated in the meeting. In addition, the responses of all experts to the other two questions (i.e. Question 1 and 6), which are 'agree' and 'strongly agree' confirmed what they said. Overall, although there were some inconsistencies, the results demonstrated that the framework meets the criteria for descriptive relevance.

8.6.4.2. Goal relevance

In general, all experts consistently responded that the framework is an effective tool to enhance disassembly process within remanufacturing companies. Question 2, 7 and 12 that were used to assess goal relevance were responded with 'agree' or 'strongly agree' with a few exceptions. Three respondents replied with 'slightly agree' to Question 7. This is partly due to the sentence of the question which is converted into a negative statement. Despite their answers were 'slightly agree', the direction of the answers from the member of experts still meet expectation although at lesser degree compared to Question 2 and 12.

One of experts that participated in validation pointed out that the Quadrant II and IV are both valid for the company where he works. His company (whose main business is remanufacturing transmissions for passenger car, trucks, light commercial vehicles, buses and coaches) also remanufacture wind turbines as a side job. He admitted that his company cannot survive if it remanufactures wind turbines only. The statement was supported by all his colleagues. Thus, Quadrant IV, in which there no case study located in this quadrant, has been validated by experts participated in the discussion. Another comment came from a member of panel expert who stated that remanufacturers have applied the framework in their daily operations. However, not all of them understand the framework in a formal way.

8.6.4.3.Operational validity

According to all members of panel expert, the findings for this criterion meet operational validity. This is indicated with the responses to the questions meet expectation. The responses were mixed from 'slightly agree' to 'strongly agree for Questions 3 and 13. Question 8, which uses a negative statement, the members of expert panel responded 'strongly disagree' to 'slightly disagree'. All the experts answered the questions as expected except one person. This expert responded 'slightly agree' to the question '*I find the framework above difficult to follow*'.

When the researcher clarified to her, she replied that it is very difficult to change existing operations due to high cost to make changes. But the respondent supported the opinion from the researcher which stated that in the long term, changing existing disassembly operations can increase efficiency that result in higher profitability. In addition to this reason, the responses to the other two other questions (Questions 3 and 13) from all experts were as expected. They all responded slightly agree, agree or strongly agree. Since the majority of respondents were agreed that the framework can be implemented, it can be concluded that the framework proposed in this study is operationally valid.

8.6.4.4. Non-obviousness

This criterion attempts to assess to what extend the framework developed in this study meets or exceeds the complexity of common sense theory already used by practitioners. The results of validation demonstrate that there is not any conflicting opinion regarding this criterion. Members of the panel expert agreed that the framework helps managers to understand various strategies for carrying out disassembly processes (Question 4) and supports managers to make better decisions (Questions 14).

Only one expert whose response is slightly different from that of others. He responded 'slightly agree' to the question '*There are many major issues missing from the framework*' (Question 9) but it was not clear what was missing from the framework. One of the possible explanations could be that the need to include the details of product attributes in the framework because there has been a discussion regarding the need to do this during the meeting.

However, the framework presents high level findings only and it has covered product attributes. As has been discussed earlier in this chapter, product attributes consist of a number of dimension such as number of components, type of materials, product structure, which are all have been summarised into 'product complexity'. The details of the framework have been presented in previous sections in this chapter. Thus, although product attributes are not presented explicitly in the framework, they are not missing because they have been considered during the framework development.

Opinions from the rest of panel members contradicted to his response to the questions (Question 9). Other 5 experts responded 'disagree' and an expert decided ‘strongly disagree’. These answers indicate that the framework meet non-obviousness criteria from the experts’ point of view. Thus, the majority of the members of expert panel agreed that there is no major issue missing from the framework.

8.6.4.5. Timeliness

All the experts responded positively but with different degree of acceptance to Question 5, 10 and 15. The responses were distributed evenly between ‘agree’ and ‘strongly agree’. Responses to the negative statement in the instrument (Question 5) were predominantly ‘disagree’ which indicate that the framework is valid from timeliness criterion.

In addition to this, there were 4 members of management team from an OEM remanufacturer who participated in group discussion for validation. The fact that they were willing to spend time and share ideas during busy time also can be taken as a consideration regarding the importance for the framework. One of the expert stated that the degree of the relevance of the framework becomes higher for companies that just set up remanufacturing business. Overall, it can be concluded that the framework proposed in this study is relevant to industrial practices.

Some members of expert panel provided suggestion regarding how the framework is presented. One of the members of expert panel provided a comment regarding the way the framework is presented. She stated that it is understandable that the framework is quite simple because it is a high level finding of this study. The framework should be accompanied with more detailed explanation in a separate document in case readers would like to read in more details. The document is important particularly for readers who do not have knowledge and expertise in remanufacturing.

Table 8.5. Results of validation using a panel of experts

Criteria	No. in the instrument	Questions to respondents	Strongly Disagree	Disagree	Slightly Disagree	Slightly agree	Agree	Strongly agree
Descriptive relevance	1	The framework closely represents real practice in remanufacturing companies.					5	2
	6	Disassembly strategies presented in the framework above are important for remanufacturing companies.				3	1	3
	11	*The framework above does not represent disassembly strategies to any great extent.*	1		2	2		2
Goal relevance	2	The disassembly strategies presented in the framework are important for remanufacturing companies.				1	2	4
	7	*Not understanding the disassembly strategy framework above may cause remanufacturing companies adopt the wrong strategies.*				3	2	2
	12	The disassembly strategies presented in the framework are useful in some way.				1	4	2
Operational validity	3	The disassembly strategy framework can be implemented in real practice.				3	4	
	8	*I find the framework above is difficult to follow.*	1	2	3	1		
	13	The framework can be used to help remanufacturers improve disassembly.				3	3	1
Non-obviousness	4	The framework helps me to understand the various strategies for carrying out disassembly processes.				3	2	2
	9	*There are many major issues missing from the framework.*	1	5		1		
	14	The framework above looks like it has potential to help managers make better decisions.				2	5	
Timelines	5	*The framework is not useful for remanufacturing companies in organising present operations.*	1	3	1	2		
	10	The disassembly strategy framework described above is an important area to address.			3	1		3
	15	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.				2	4	1

Overall, the conclusions of this validation are two folds. First, the study has produced relevant output for industrial practices. The expertises possessed by the experts have confirmed that the results of this study are relevant and useful for industrial practices. Second, it has passed the test for replication logic. The members of expert panel who have extensive knowledge regarding remanufacturing practices confirmed that the findings of this study are replicable to other companies.

8.7. Summary of Chapter 8

This chapter aimed to develop a framework of disassembly for remanufacturing companies, which is based on factors that have been identified from empirical findings. The development of this framework was carried out in several steps. First, the factors were classified into two main factors – the stability of cores supply and product complexity. A discussion regarding how the factors was also provided. Afterwards, these two main factors were used as the x-axis and y-axis of a diagram. Second, the case companies were plotted into a diagram based on the level of stability of cores supply and products complexity. Third, the common characteristics of case companies within the same quadrant and differences with other quadrants were both analysed. The purpose of this analysis was to identify the strategies for the disassembly processes of remanufacturers within and across different quadrants. In the discussion section, how the remanufacturers from different quadrants can expand to other diagrams was discussed. The obstacles and advantages of the expansions were both discussed.

In the final chapter, there will be an assessment about the quality of the research design and a discussion whether this study has fulfilled the criteria for the assessment. Finally, the direction for future research, limitations of the research and the implications for managers will be discussed.

9. CONCLUSSION

The previous two chapters discussed the research findings in light of empirical evidences from the field, and findings from literature were discussed in more detail. In this last chapter, several points will be discussed, including an assessment of the quality of the research, its contributions to knowledge and the possible directions of future research.

9.1. Assessing the quality of the research

This study meets all of the criteria for ensuring the validity and reliability of the research output; the criteria used to assess the research quality are discussed in Chapter 4. This chapter will discuss how the methods and techniques used to ensure research quality were applied in this study. As discussed in Chapter 4, there are several accepted measures that can be used to assess the quality of the research process used in case studies; these include: construct validity, internal validity, external validity and reliability (Easterby-Smith et al. 2012; Yin 2009; Healy & Perry 2000). Table 9.1 describes how the present study achieves these criteria.

Validation processes were carried out during several phases, including during data collection and analysis; the validity of data was clarified by the researcher at the point of collection. Communication with participating companies was maintained via e-mail in case it was not possible to revisit the company. The meaning of the data sometimes appeared clear during data collection in the field, yet later in-depth analysis and comparison with the literature revealed ambiguities. In this instance, the researcher clarified this situation under question during the next interview with the relevant informants. Thus, the iterative process of data analysis and data collection ensures that the data collected from the fields is valid. Other methods used include triangulation of data sources and data form. Details of how this study addresses validity and reliability issues are presented in Table 9.1.

Table 9.1. Techniques for establishing research validity and reliability

No.	Case study criteria	Case study techniques	How was this achieved in this research	Phase of research in which techniques occur	References to the thesis
1.	Construct validity	Use of multiple sources of evidence	Using data triangulation to collect the data from multiple sources and at different times.	Data collection	Chapter 5, Appendix IVA, IVB, IVC, IVD and IVE.
		Establish a chain of evidence	Developing constructs by means of a systematic literature review to provide a better construct validity.	Literature review	Chapter 5
			Using case study notes, combined with a research diary, to document ideas and thoughts.	Data collection	Chapter 6, Appendix IVA, IVB, IVC, IVD and IVE.
			Clarifying the findings in the subsequent company visits and maintaining contact with the key informants in case there were any unclear findings.	Data collection	Chapter 6, Appendix IVA, IVB, IVC, IVD and IVE.
2.	Internal validity	Pattern matching	Using tables and figure to identify pattern matching between the cases and developing explanations for the patterns.	Data analysis	Chapter 7, Chapter 8
		Explanation building	Using robust data analysis, through an iterative process, between data collection, literature review and any relevant theories.	Literature review, data analysis	Chapter 5, 6, 7 and 8.
		Addressing rival explanations	Discussing other possible explanations of emerging patterns by using literature review.	Data analysis	Chapter 6, 7 and 8.
			Conducting case analysis, followed by cross-case analysis to predict similar and different patterns.	Research design	Chapter 6, 7 and 8.
3.	External validity	Using replication logic in multiple case studies	Using multiple case studies that were designed to develop replication logic, via five cases. The companies were not selected randomly. The composition of the case companies was designed to enable the researcher to carry out direct replications, i.e. predict similar results – and indirect replications, i.e. predict different results.	Research design	Chapter 7, Chapter 8
		Review by panel of experts	Reviewing the findings by a panel of experts using criteria developed by Thomas and Tymon (1982). The experts consisted of experienced practitioners and researchers that have extensive knowledge in remanufacturing field.	Findings validation	Chapter 8, Appendix V.
4.	Reliability	Using case study protocol	Using case study protocol to ensure that the researcher collects all of the necessary data	Data collection	Appendix III
		Developing case study database	Developing a case study database, case study reports, cross-case analysis, pattern matching and enfolding literature to ascertain that the research findings are reliable.	Data collection	Chapter 7 and 8, and Appendix IVA, IVB, IVC, IVD and IVE.
			Using iterative tabulation of evidences with a literature review. The findings from each company were analysed against existing literature.	Data analysis	Chapter 6.

Source: adapted from Yin (2009)

During the data analysis stage, the core activity of theory building (Eisenhardt 1989), the researcher adopted techniques suggested by Eisenhardt and Graebner (2007) and Voss et al. (2002), namely combining narrative descriptions with graphs, figures and tables to ensure that both objective and rigorous conclusions are produced. Visual data presentations, such as graphs and figures, ensure that all of the relevant data is captured, as these tools can communicate rich data better than a narrative description.

In this study, several techniques identified in the literature (Healy & Perry 2000; Meredith 1998; Yin 2009) were implemented to ensure that the process meets the criteria of a rigorous study. Extensive literature reviews were carried out as part of this study with the purpose of: (1) identifying a research gap (Wacker 1998); (2) guiding the study in case of an absence of relevant theory (Barratt et al. 2011); (3) developing priori constructs for the deductive study of Research Question 1, (Eisenhardt & Graebner 2007; Meredith 1998; Eisenhardt 1989); and, (4) iteratively comparing the empirical evidence with the results of other research (Eisenhardt 1989; Voss et al. 2002). The uses of the literature review were not limited to the purposes outlined above; the literature review was used at every stage of the research process.

9.2. Research objectives revisited

Two research questions were proposed from the outset. These are, first, to explore the factors affecting the disassembly strategy for remanufacturing; second, to develop a framework for the disassembly strategy of remanufacturing companies. The research objectives of this study were derived from the research questions, which arise from a gap in existing studies (Creswell 2014; Wacker 1998). A summary of the objectives and a summary of to what extent they have been achieved are as follows:

1. *To identify what has been understood about disassembly in current studies and the drawbacks.*

   Existing definitions of disassembly in the literature focus on product attributes only, such as type of materials, structure of products, number of components and so on. These are all 'hard' factors affecting disassembly, related to the physical activities of disassembly. On the other hand, other factors relating to organisational characteristics and process choices are overlooked in existing studies, and so are covered in this study. This is a unique aspect of the study, in that it combines both soft and hard factors as well as examining disassembly from a strategic perspective.

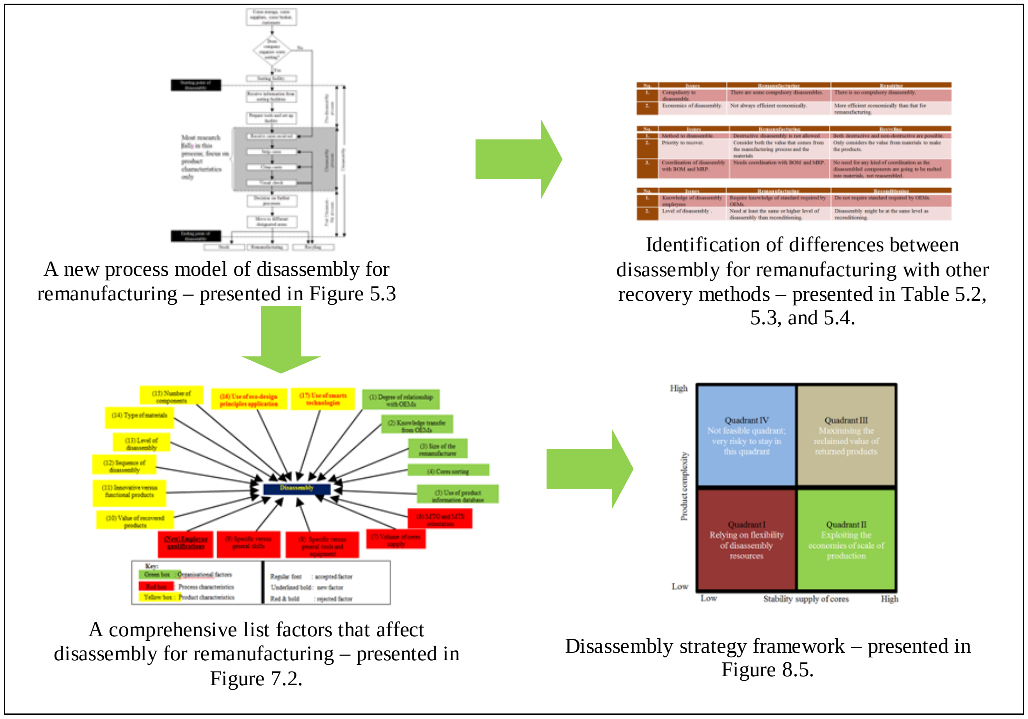
2. *To develop a model of disassembly that includes how disassembly in the new process model affects other activities in remanufacturing and how disassembly for remanufacturing differs from that of other recovery methods.* The starting point for the research is the new process model of disassembly – presented in Figure 5.3 – that was developed in reference to the drawbacks of existing definitions. Section 5.4 discussed how it affects other remanufacturing process, and a summary of how it differs from disassembly for other recovery methods was presented in Tables 5.3, 5.4, and 5.5.
3. *To examine the factors that affect disassembly.* This not only covers issues relating to product attributes, but also encapsulates other factors derived from organisational characteristics and process choices. Considering that this study is theory driven, the research must be well grounded in existing theories (Eisenhardt & Graebner 2007). A sound and systematic literature review supports this research in its construction of factors that affect disassembly; this was discussed in Chapter 5. A total of 17 factors were identified using existing literature; of these factors, 15 are confirmed, 2 are unconfirmed. In addition to these, 1 factor emerged from empirical findings. These are the most comprehensive list of factors identified in existing studies.
4. *To analyse disassembly strategies that have been adopted by remanufacturing companies*. Remanufacturing companies adopt different strategies to carry out their disassembly processes. The framework of disassembly strategies is depicted in Figure 8.5.

9.3. Contribution to knowledge

There are several outputs of this study, mainly derived from the achievement of the research objectives, which result in contributions to knowledge. The original contributions to knowledge made by this research is the fact that *it is the first time* that:

1. *A specific model of disassembly for remanufacturing has been determined.* It clarifies the start and end point of disassembly, how it interplays with other processes in remanufacturing and what activities are covered at each stage of the disassembly process.
2. *Differences between disassembly for remanufacturing and that for repairing, reconditioning and recycling have been identified.* This new knowledge provides new understanding and clarifies confusion regarding the differences of disassembly for various recovery methods. It also provides guidance for managers who intend to set up disassembly facilities for remanufacturing.
3. *A comprehensive list factors affecting disassembly in remanufacturing that combine hard and soft factors as well as examining disassembly from a strategic perspective, have been identified.* The outcome of this research allows disassembly to be recognised as 'a process' that requires comprehensive analysis, not only as the 'physical activity' of breaking down products into components.
4. *A framework of disassembly strategies for remanufacturing companies has been developed.* Validation from academics and practitioners confirms the usefulness and relevance of the framework for practical application. Thus, the framework not only provides an original contribution to knowledge but also to the practical field.

It is important to note that the contributions to knowledge that are briefly described above are related one another. The relationship between the pieces of knowledge is important in order it can develop a body of knowledge. This is expressed by Whetten (1989), who quotes Poincare (1952) stating that, ‘Science is facts, just as houses made of stone…. But a pile of stones is not a house and a collection of facts is not necessarily science’. Therefore, logical reasoning that explains how a relationship between different concepts is needed to support the development of knowledge. The relationship between the contributions to knowledge contained within this research is depicted graphically in Figure 9.1.



A new process model of disassembly for remanufacturing – presented in Figure 5.3

Identification of differences between disassembly for remanufacturing with other recovery methods – presented in Table 5.2, 5.3, and 5.4.

A comprehensive list factors that affect disassembly for remanufacturing – presented in Figure 7.2.

Disassembly strategy framework – presented in Figure 8.5.

Figure 9.1. Summary of the contributions to knowledge

As shown in Figure 9.1, the starting point of the contribution to knowledge is the new process model of disassembly. From here, the boundaries of disassembly are determined and a new process model of disassembly is developed. Then, still using the new process model, the factors affecting disassembly are identified. Last, a disassembly strategy framework is developed based on the factors affecting disassembly; in this framework, ‘disassembly’ refers to the new process model of disassembly developed in this study.

9.4. Research limitations

Any piece of research will always have some drawbacks that cannot be controlled by the researcher, and this study is no exception. Therefore, the researcher strives to find methods of minimising these weaknesses, so that the validity and reliability of the study can be improved. The weaknesses of this study are:

1. There is a maximum of two case studies in each quadrant in the framework of disassembly strategies developed in this study. Future research could use more case studies, either to test or extend the framework. A survey is another alternative that

could be used to test whether the resulting theory is valid. Although the number of case studies used in the research is sufficient from a theoretical perspective (Eisenhardt 1989; Meredith 1998), increasing the number could generally improve the findings, although it would not alter the conclusions. The researcher has strived to collect and analyse the data carefully, as much as possible, by means of triangulation and by combining several data analysis techniques.

2. This research investigates only UK-based companies. A further study could embrace the use of an international context by carrying out testing in different countries. Any differences between countries might affect the disassembly process, as each country has variation in their level of technological adoption, labour costs, patterns of product use by customers, and so on.

9.5. Implications for practice

This research offers some practical relevance to industries, which is also one of the criteria for good research in operations management field (Karlsson 2009; p. 13). These criteria are:

1. Managers of remanufacturing companies should have a sense of entrepreneurship. They should be able to identify new products to market by OEMs and what opportunities are available from after-market products. A good understanding of this knowledge will lead to an increased capability to prepare resources for disassembly, including facilities, equipment and human resources.
2. Managers of remanufacturing companies should balance their priority between the stability of cores supply and product complexity. Complex products typically have a high potential reclaim value, so that remanufacturing companies can invest some of their resources into developing R&D, training and infrastructure. However, companies cannot process a large number of products with high complexity. On the other hand, products with low complexity are easier to process, but the managers should be aware of the cost of disassembly as these products typically have lower profit margins.

3. For OEM managers, it is important to develop relationships with remanufacturing companies to identify which parts or components most commonly wear out, how to improve their durability, and how to improve design for disassembly so that the life of the products can be extended. This knowledge can only be developed by the remanufacturers (Lind et al. 2014).

9.6. Implications for theory and future research directions

This study offers insights that contribute to debate among academics in this field. There is a dispute as to whether OEMs should adopt design for disassembly. OEMs hesitate to carry out remanufacturing activities, instead focusing on manufacturing new products (Ferguson & Toktay 2006). Although the adoption of design for disassembly helps them to repair, maintain and disassemble products, it is not always beneficial for them. The adoption of design for disassembly may increase manufacturing costs, which is not good from a manufacturing perspective. On the other hand, it reduces remanufacturing costs, increases component interchangeability and, eventually, reduces the selling price of remanufactured products (Wu 2013). In short, the adoption of design for disassembly poses a dilemma for OEMs.

OEMs are more likely gain benefit from remanufacturing products that have high complexity (Martin et al., 2010) and therefore it is more likely that OEMs will adopt design for disassembly for complex products. The complexity of products creates certain barriers for independent remanufacturing due to the knowledge required of the products (Hammond et al. 1998). OEMs are in a better position to access cores from customers in comparison to independent remanufacturers (Sherwood et al. 2000). Complex products are more likely to involve intellectual property rights than simple ones, and OEMs have an interest in protecting them (Subramoniam et al. 2010; Martin et al. 2010). Disassembly is the key process through which intellectual properties are endangered; thus, remanufacturing and disassembling products in-house as well as keeping the products within the control of OEMs is a wise strategy to protect intellectual property.

In terms of residual value, complex products offer benefit to OEMs, which seek to adopt design for disassembly in a number of ways. OEMs have a 'mass production' mentality (Subramoniam et al. 2009) and the high value derived from complex products can make low volume cores become more interesting. High residual economic value from cores can offset the higher production cost that might occur due to the adoption of design for disassembly. Also, this high residual value makes adoption of technology that support disassembly become feasible economically because it is currently expensive (Sundin et al. 2012). For example, Ilgin et al. (2011) requires that the cost of embedded technology supporting disassembly should not exceed $28.64 per product, and the residual value should be significantly higher than that figure.

In addition to theoretical implication outlined above, this study points to possible opportunities for research to be pursued in the future. Some of these examples are discussed below.

9.6.1. Interactions between the factors affecting disassembly

Factors that have been identified as affecting disassembly from literature presented in Chapter 7 could be a good departure for deeper investigations. Future investigations could explore whether the factors that affect disassembly are confirmed in empirical findings and whether there are any new factors that could emerge.

In addition, investigators could go further by analysing how the factors might be interplay. For example, companies that disassemble a wide variety of cores would employ multi-skilled workers and equip them with multi-purpose tools (Seitz & Peattie 2004) while companies that receive a large number of homogenous cores could adopt automated disassembly that is operated by specialised workers (Seliger et al. 2004). A new research that investigates the interaction between these factors could be useful in helping remanufacturers to understand which factor affects what, and the factors that are the most influential could then be controlled. From here, researchers could develop an index that would be useful for policy makers. The capability to control the most significant factor would be useful for remanufacturers and help them to manage disassembly process more easily.

Also, future research could test the framework developed in this study using survey. Survey has been mentioned as an appropriate method to test a theory (Meredith 1998; Voss et al. 2002). The method offers a wide coverage on the population but at the expense of the richness of the data. However, if the researcher interested to gain a depth understanding, Delphi Method combined with interview with the participants would offer deeper insights.

9.6.2. Knowledge transfer from contract remanufacturers to OEMs

A lot of literature points out the reluctance of OEMs to share knowledge to contract remanufacturers because it might endanger their intellectual property (Martin et al. 2010; Subramoniam et al. 2009). OEMs attempts to hinder independent remanufacturers to enter after-market business (Lind et al. 2014). In fact, OEMs can improve remanufacturability of products by incorporating knowledge which they have gained from remanufacturers (Ferrer & Whybark 2000). This knowledge is unique and cannot be obtained from parties other than remanufacturers, since some knowledge is created only by remanufacturers (Lind et al. 2014). This knowledge could be potentially lost unless it is used by OEMs. A short discussion presented in Saavedra et al. (2013) point out how OEMs and independent remanufacturers can collaborate and gain mutual benefit. The research opportunity here is, how can appropriate relationships be formed that will support the transfer of knowledge from contract remanufacturers to OEMs, and vice-versa, and create win-win solutions?

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APPENDIX I – Glossary

Cores	:	Products that have been used by customers, or damaged products identified during distribution that are sent back to dealers, OEMs, or remanufacturers to be recovered.
Reverse logistics	:	The process of planning, implementing and coordinating the backward flow of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal (Rogers and Tibben-Lembke 1999)
Partial disassembly	:	The process of dismantling cores, step-by-step, without any prior specification as to when the process will stop. Not all components are taken out from products in this disassembly.
Selective disassembly	:	The process of dismantling the desired components of a product without causing any damage to the parts and products. Employees carrying out selective disassembly have a specific plan at the outset regarding which components taken out and to what level the disassembly should be carried out.
Full disassembly; total disassembly; complete disassembly	:	The process of dismantling products into the lowest level, where all the constituent parts are separated.
Disassembly process	:	Disassembly encompasses the pre-physical disassembly activities, disassembly activities and post-disassembly activities. It begins when the company receives information that triggers disassembly, and finishes when all disassembled components are located in designated areas, either for further processes in remanufacturing or for stocks.
Pre-physical disassembly activities	:	The activities of setting up the tools, equipment and facilities for the disassembly process. This process begins when the disassembly shop floor receives information regarding the cores, either from the sorting facilities, cores suppliers or from other departments within the company. Based on this information, the pre-disassembly process begins, even where the cores have not yet arrived in the disassembly facility.

Physical disassembly activities	:	The physical activities that are performed to break products down into their constituent parts. Most of the activities carried out in this process involve disconnecting joints.
Post-physical disassembly activities	:	The activities that are intended to manage the components resulted from disassembly process. These include separating, handling and moving the components for further processes in remanufacturing, such as cleaning, testing and inspection.
Active disassembly technology	:	Technology that is embedded into products to make the disassembly process easy, clean and non-destructive, with quick and efficient component separation. The term is synonymous with Active Disassembly using Smart Materials.
Engine health management system (EHMS)	:	Information systems and technology that monitor the performance and condition of jet engines. The technology uses 20-30 parameters attached to the engines that send signals to ground operators regarding the performance of the engines during flights. The parameters that are monitored are, among others: temperatures, pressures, speed and vibration. The technology functions to ensure that they are within the tolerance range.
OEM remanufacturers	:	Manufacturers that carry out remanufacturing alongside the manufacturing process of new products.
Contract remanufacturers	:	Remanufacturers who, under the license of OEMs, carry out remanufacturing of the OEMs’ products and often, but not always, receive technical support from the OEMs.
Independent remanufacturers	:	Parties who remanufacture other people's products without technical support or licenses for direct sales into the aftermarket.

APPENDIX IIA – List of articles for systematic literature review

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APPENDIX IIB – Classification of factors affecting disassembly identified from literature

No.	Themes	(CODE) Factors	Relevant references from the systematic review
1.	Organisational charateristics	(OC1) Degree of the relationship with OEMs	Gerrard & Kandlikar (2007); Haynsworth & Lyons (1987); Sherwood et al. (2000); Westkamper (2003); Wu (2012); Wu (2013)
		(OC2) Knowledge transfer from OEMs	Westkamper et al. (1999); (Westkamper 2003)
		(OC3) Size of the remanufacturer	Sherwood et al. (2000); Williams et al. (2001)
		(OC4) Cores sorting	Du et al. (2012); Kerr & Ryan (2001); Shu & Flowers (1999); Simolowo et al. (2011); Tagaras & Zikopoulos (2008); Yu et al. (2011); Vadde et al. (2011); Williams et al. (2001); Zikopoulos & Tagaras (2008); Loomba & Nakashima (2012); Ferrer & Whybark (2000)
		(OC5) Product information database	Chung & Wee (2008; Chung & Wee (2010); Ijomah & Chiodo (2010); Lee & Chan (2009); Shimizu et al. (2010); Simolowo et al. (2011); Westkamper (2003); Westkamper et al. (1999); Ilgin et al. (2011)
2.	Process choices	(PC1) Make-to-order (MTO) versus make-to-stock (MTS) orientation	Guide Jr. et al. (1999; Langella (2007); Tang et al. (2007); Ketzenberg et al. (2003); Abbey et al. (2013) ; Huajun et al. (2008) ; Inderfurth & Langella (2005) Ondemir & Gupta(2014b) ; Ondemir & Gupta (2014a)
		(PC2) Volume of cores supplies	Franke et al. (2006); Kerr & Ryan (2001); Jaber & El Saadany (2011); (Behdad & Thurston 2012); (Behdad et al. 2012)
		(PC3) Specific versus general tools and equipment	Desai & Mital (2005); Du et al. (2012); Franke et al. (2006); Gungor & Gupta (1998); McGovern & Gupta (2007); Moore et al. (1998); Seliger et al. (2004); Siddique & Rosen (1997); Westkamper et al. (1999); Ijomah & Chiodo (2010); Sundin et al. (2012); Kernbaum et al. (2009); Ryan et al. (2011)
		(PC4) Specific versus general skills	Westkamper et al. (1999); Ijomah & Chiodo (2010); Ayres et al. (1997); Gerrard & Kandlikar (2007); Tang et al. (2007); Guide et al. (2005); Jaber & El Saadany (2011); Eguia et al. (2013); Ferrer & Whybark 2000); Ilgin & Gupta (2010); Ferrer 2003)

		(PA1) Value of recovered products	Du et al. (2012; Ferrer & Whybark (2001); Ferrer (2001); Guide Jr. et al. (1999); Jun et al. (2012); Li & Rong (2009); Seliger et al. (2004); Tang et al. (2002); Yu et al. (2011); Tian et al. (2012); Vadde et al. (2011); Westkamper et al. (1999); Williams et al. (2001); Go et al. (2011); Ilgin et al. (2011); Schulz & Ferretti (2011); Gungor & Gupta (1998); Pandey & Thurston (2009); Inderfurth & Langella (2005); Ferrer (2003); Tuncel et al. (2012)
		(PA2) Innovative versus functional products	Du et al. (2012); Guide et al. (1997); Hu et al. (2011); Lambert (2002); Westkamper (2003)
		(PA3) Sequence of disassembly	Adenso-Díaz et al. (2008); Gerrard & Kandlikar (2007); Gungor & Gupta (1998); Gungor & Gupta (2001); Johnson & Wang (1995); Johnson & Wang (1998); Langella (2007); Kang & Hong (2012); Ma et al. (2011); Moore et al. (1998); Veerakamolmal & Gupta (2002); Harper & Rosen (2001); Shimizu et al. (2010); Siddique & Rosen (1997); Simolowo et al. (2011); Smith & Chen (2011); Smith et al. (2012); Tang et al. (2002); Tian et al. (2012); Vinodh et al. (2012); Zhang et al. (2004); Reveliotis (2007); Rickli & Camelio (2014); Han et al. (2013); Yeh et al. (2012); Behdad & Thurston (2012); Tsai (2012); Luyima et al. (2012); Eguia et al. (2013); Fang-yi (2009); Shimizu & Yamada (2009); Zussman & Zhou (2000); Li et al. (2013).
3.	Product attributes	(PA4) Level of disassembly	Desai & Mital (2005); González & Adenso-Díaz (2005); Guide et al. (1997); Gungor & Gupta (2001); Johnson & Wang (1995); Kang & Hong (2012); Lee et al. (2010); Ma et al. (2011); Smith & Chen (2011); Smith et al. (2012); Sutherland et al. (2002); Tang et al. (2002); Tian et al. (2012); Xanthopoulos & Iakovou (2009); (Zhang et al. 2004); Guide et al. (2005); Han et al. (2013); Dingeç & Korugan (2013); Luyima et al. (2012); Fang-yi (2009); Rios & Stuart (2004); Zussman & Zhou (1999)
		(PA5) Type of materials	Desai & Mital (2005); Gerrard & Kandlikar (2007); Guide et al. (1997); Ilgin & Gupta (2011); Johnson & Wang (1998); Zhang et al. (2004); Zwolinski & Brissaud (2008); Go et al. (2011).
		(PA6) Number of component	Adenso-Díaz et al. (2008); Güngör (2006); Jun et al. (2012); Kang & Hong (2012); McGovern & Gupta (2007); Veerakamolmal & Gupta (2002); Harper & Rosen (2001); Sherwood et al. (2000); Vinodh et al. (2012); Williams et al. (2001); Zhang et al. (2004); Schulz & Ferretti (2011)
		(PA7) Ecodesign principles	Chung & Wee (2008); Chung & Wee (2010); Gerrard & Kandlikar (2007); Güngör (2006); Hu et al. (2011); Ijomah & Chiodo (2010); Kerr & Ryan (2001); Sherwood et al. (2000); Shu & Flowers (1999); Siddique & Rosen (1997); Sutherland et al. (2002); Vinodh et al. (2012); Williams et al. (2001); Wu (2012); Wu (2013); Xanthopoulos & Iakovou (2009); Zwolinski & Brissaud (2008); Go et al. (2011); Ferrer (2001); Abbey et al. (2013); Sundin et al. (2012); Plant et al. (2010); Ilgin & Gupta (2010); Gehin et al. (2008); Sundin & Bras (2005)
		(PA8) Smarts technologies	Chiodo & Ijomah (2012); Ijomah & Chiodo (2010); Ilgin & Gupta (2011); Lee et al. (2010); Smith & Chen (2011); Westkamper (2003); Hendrickson et al. (2010); Ondemir & Gupta (2014a)

APPENDIX III – Case study protocol

A STRATEGIC OPERATIONS FRAMEWORK FOR DISASSEMBLY IN REMANUFACTURING

SECTION I – OVERVIEW OF THE STUDY

Objectives of the study

Disassembly is a part of the remanufacturing process that recovers used products and restores them to as-new condition (Lund 1984), and is the main distinguishing feature between product recovery activities and conventional manufacturing operations. In conventional manufacturing, there is only assembly process, whereas in remanufacturing there are both disassembly and assembly processes. Furthermore, disassembly process is the main gateway of information in remanufacturing, therefore improvements in disassembly will help to improve the other remanufacturing processes (Junior & Filho 2012).

Processes undertaken in conventional manufacturing, such as component sorting, testing, assembly and inspection can also be adopted, to some extent, by remanufacturing operations. However, the disassembly process does not exist in conventional manufacturing. For this reason, the methods, techniques, tools and equipment of manufacturing are very difficult, if not impossible, to adopt in disassembly for remanufacturing. Additionally, the disassembly process may require further tools and equipment in order to minimise the likelihood of causing damage, as many products are designed with only assembly in mind (Sundin & Bras 2005).

Current research that investigates disassembly for remanufacturing highlights product attributes only, and overlooks other factors, such as organisational characteristics and process choices. The importance of these factors is pointed out by Bras and McIntosh (1998) and Östlin et al. (2008) but no research appears, yet, to address this gap. Organisational factors, including the relationship with Original Equipment Manufacturers (OEMs) and types of remanufacturers, should also be considered. Similarly, production capacity, employee skills, tools and equipment, amongst other factors, must also be investigated. This study aims to address this gap and investigates disassembly strategy using a strategic standpoint that considers organisational characteristics, process choices and product attributes.

This research does not aim to offer a static formula to be applied as-is, but rather to provide generic guidance that could be useful for managers of remanufacturing companies drafting disassembly strategy. Two research questions are proposed, which arise from a critical analysis of the existing literature. The research questions are:

1. What are the factors that affect disassembly for remanufacturing?

2. How do remanufacturing companies manage disassembly based on the factors affecting it?

SECTION II – FIELD STRATEGIES

Field visits follow a sequence of processes, as presented in Table III.1. Field strategies consist of phases 1 – 3, which regard preparation before entering the field and are described in this section. Section III will present phases 4 – 6, which explain how to collect data in the field and how to conduct analysis.

Table III.1. Phases of data collection and analysis

Section	Phase	Topics addressed
Section I	Overview of the study	Objectives of the study
Section II	Phase 1- Getting started	Unit of analysis and selection of case companies Desk research
	Phase 2 - Developing interview strategy	Skills required during interview processes Arranging interview
	Phase 3 – Developing interview questions	Orientation questions Main questions Closing interview and post-interview
Section III	Phase 4 - Case company visit	Conducting the interview Collect secondary data Shop floor visit Closing interview and post-interview
	Phase 5 - Case studies, standard write up	General description about the operations of the case companies
	Phase 6 - Case study analysis	Compiling data Disassembling data Reassembling data Interpreting data Drawing conclusions
	Phase 7 - Review and validation	Review and feedback from interview participants

Phase 1 – Getting started

Data collection affects the quality of data and influences the rigor of the study. To ensure robust data collection, the researcher undertook a series of steps before he entered the field.

Unit of analysis and selection of case study companies
The selection of companies to be included in the study is aimed at ensuring that the subjects will contribute relevant insights. The researcher does not only set up the target of number of case, but also needs to ensure that the composition of the samples represents different background to allow direct and indirect replications to be carried out. Companies of different sizes, which remanufacture different products and have different degrees of relationship with OEMs are selected to allow the replications.

Unit of analysis is the main entity that will become the focus of an investigation (Yin 2009). In this study, the unit of analysis is the main product remanufactured by the case companies. Here, the main products refer to product categories that are remanufactured in the highest volumes by the companies. Product categories are selected as the unit of analysis rather than product models, types or brands because these have too much variation, and so it would be difficult to identify emerging patterns. The investigation is focused on the main product only because it is the core business of the case companies.

Desk research
Desk research is undertaken mainly to obtain a priori information regarding potential case companies. In this step, information available to the public can be accessed, such as an overview of company operations, details of products that are remanufactured, and relationship of case companies with OEMs. Internet research and company profile publications are the main resource in assessing whether a company meets the criteria for inclusion in the research.

Phase 2 - Developing interview strategies

The researcher prepared a set of questions influenced by the literature, which the informants will be asked. These questions should not be used strictly, but rather should be able to capture any relevant issues that emerge in discussion, and allow the researcher to prompt with critical questions. The list is used to ensure that no points are missing that should be asked, and that the conversation has a clear direction. It is crucial that the researcher retrieves all data related to the relevant topics in the interview session, in order to enable him to triangulate.

Skills required during interview processes
Before conducting the interview, the researcher must be familiar with the questions, in order to be objective, unbiased, systematic and thorough. During the interview, the researcher should listen attentively, be adaptive and flexible to new emerging issues. He should also have the ability to grasp relevant information, and be free from bias or influenced by personal views. In addition to these, he needs to provide opportunities for interviewees to offer relevant information beyond answers to the specific questions asked.

Interview sessions vary for each informant, depending on how the interaction goes and what their responses are. In certain circumstances, the interview can reach saturation, whereby informants enjoy the conversation, but the responses do not address the topics in a significant way. In other circumstances, the respondent might be hesitant to give long explanations, and so only give answers to the questions asked by the researcher. To overcome this situation, the researcher must ask relevant questions based on the prepared interview guidelines.

Arranging interviews
To ensure objectivity and to enable the researcher to conduct triangulation across different informants, the interviews should be with people who are related to the issues under investigation. Even though there is no precise guidance regarding how many people should be interviewed within an organisation, the interview participants should be representative of individuals from different parts of the companies in order to allow triangulation. Before conducting the interview, there are several points that should be kept in mind:

1. Contact the interviewees before the due time and ask whether they will be available at the proposed time.
2. Add new questions to the list of questions based on the responses of previous interviewees
3. Some preliminary thoughts and analysis of researcher should be written down as notes, as soon as the data is collected.
4. Ask not only about real facts in the company, but also for their personal thoughts.

Phase 3 – Developing interview questions

The general nature of the study is inductive, but there is also a deductive element. Inductive studies allow the researcher to be more open to perceiving elaborate emerging patterns. On the other hand, the deductive nature of the study does lead the researcher in certain directions as a result of guidance drawn from the literature. For this reason, the researcher should ask questions that are based on conclusions drawn from the literature review in an explicit way (Eisenhardt, 1989). This is intended to make it clear how the constructs from literature are relevant to the empirical findings, and vice versa. Most of questions in this study are exploratory in nature, and so theyare open questions. Questions that are intended to be deductive are prepared according to the literature review, and are presented in italics, along with the code of the relevant constructs, at the beginning of the questions.

General company information

1. (OC3) What is the annual turnover of this company?

2. How many cores does your company remanufacture per year?

3. (OC3) What types of products that are remanufactured and which one is the most dominant?

4. How many employees in total and how many employees work in disassembly shop floor?

Types of relationship with OEMs

5. (OC1) Do you have contracts with OEMs? If so, could you please describe how the contracts work?

6. How to determine the price of cores?

7. Who and how to collect cores from market?

8. How to schedule arrival of cores in your factory?

9. (OC2) Do you receive support from OEMs regarding product information?

10. (OC5) Do you have product database? If so, could you please explain?

11. (OC5) Do returned cores accompanied with product history?

12. (PA2) Could you tell me to how new product introduction from OEMs affect remanufacturing and disassembly operations in particular?

Cores procurements

13. How the price of cores is agreed between your company and OEMs?

14. How does the cores acquisition price and remanufactured cores selling price affect disassembly's economic feasibility?

15. (OC4) Do you organise sorting? If so, could you please describe how it works?

16. Do you get involved in disassembly process when the cores have been delivered to disassembly shop floor? (e.g. providing information, sharing opinion, offering advice, sharing knowledge etc.)

Pre-physical disassembly activities

17. Do you receive information regarding products before they arrive in disassembly shop floor? If so, could you please explain?

18. Before the cores arrive at the disassembly shop floor, are there any possibilities that can be done by disassembly workers? (e.g. set up machinery, select tools, prepare equipment etc.).

19. (PC1) Which one more represents your company, make-to-order or make-to-stock? Could you please explain more detail?

Physical disassembly activities

20. Could you please describe how the general steps of disassembly?

21. What is the most dominant problem in disassembly?

22. Which process in remanufacturing operations that you think affect disassembly? (eg. sorting, inspection, scheduling etc.).

23. Which process in remanufacturing operations that you think are affected by disassembly? (e.g. MRP, re-assembly, purchase of new parts etc.)

24. What types of uncertainties found during physical disassembly activities?

25. How to reduce the overall disassembly time?

26. How to minimise idle capacity of disassembly process?

27. How is your strategy if you disassemble cores that have never been disassembled before?

28. (PC3) Could you please explain what tools and equipment that you use? Are they customised or general tools/equipment?

29. (PC4) Could you please explain what skills needed to carry out disassembly?

30. (PC4) How the employees obtain the skills and knowledge to do disassembly? (e.g. training, education, coaching etc.).

31. (PC4) Could you please describe whether the employees can be transferred between different jobs?

32. (PA8) Is there any technology embedded in the product that can make disassembly easier? (e.g. smart technology, active disassembly etc.).

33. (PA6) How many components embedded in the products and could you please explain how the design affects disassembly?

34. (PA7) Could you please describe if the cores have been designed with ecodesign principles? If so, how it affect disassembly?

Post physical disassembly activities

35. After disassembly process finishes, is there any other activities performed to parts? (e.g. parts movement because of large size and heavy parts, special treatment due to hazard etc.)

36. How to decide that parts from disassembly process are processed further or for inventory?

37. How to decide (what considerations do you have) that disassembled parts are intended either for further process or for inventory?

Material management in disassembly

38. How do you store cores in every phase of disassembly process?

39. How to manage cores obsolescence in the inventory?

40. How to avoid overstock or out of stock, and what can you do if it happens?

41. Could you please describe how do you organise coordination with other processes in remanufacturing **-** i.e. reassembling, cleaning, testing?

Sequence and level disassembly process

42. (PA4) What is the level of disassembly, full, partial or selective? Why?

43. (PC2) How do you decide the number of cores that are disassembled?

44. (PC1) Do you think volume of cores affect disassembly? If so, why and how?

45. Could you please tell me how do you assess that disassembly cores are economically efficient?

46. (PA3) Could you please explain how do you decide which parts should be assembled first?

47. (PA3) What if the part that you intended to take out is located in the last sequence of disassembly process?

48. (PC2) Is there any advantage if the disassembly volumes reach certain number? Could you please explain

Shop floor worker flexibility

49. In your opinion, to what extent is the importance of staff flexibility?

50. What is the bottleneck in disassembly process? Could you please explain…

51. Do you have specific technology that makes your disassembly process more efficient?

52. How do you organise scheduling of disassembly operations with regard to uncertainty of incoming cores?

Shop floor disassembly performance

53. Describe the general method of performance measurement in your disassembly?

54. How do you measure disassembly cost for each product?

55. In your opinion, what can be done to improve the overall performance of disassembly process?

Interview questions for purchasing staff (MRP):

56. How does disassembly process affect the department where you work?

57. What types of uncertainties come from disassembly process?

58. Do you get involved in disassembly process? (eg. providing information, sharing opinion, etc.)

59. To what extent disassembly process influences the purchase of new parts?

60. How to make decisions which type of parts that should be bought and in what number? Do you communicate with staffs in disassembly shop floor to make this decision?

61. How do you manage lead time uncertainty in ordering new parts?

62. What if there is not any new part available in the market?

63. In which situation do you chose to buy components instead of remanufacturing parts?

Due to the general nature of the research is exploratory, the questions tend to be open to give opportunity for informants. To do this, follow up questions are prompted to gain further understanding of the responses. The floating prompts are:

Could you please give an example when...

Would you tell me more detail about...

Could you me clarify about...

SECTION III – DATA COLLECTION AND ANALYSIS

Phase 4 - Case company visit

Conducting interviews

During the interview, the responses are recorded and documented using handwritten notes. Subsequent to each interview session, the researcher adds comments in the notes that are not possible to write during the interview. This action should be conducted immediately, just after the researcher leaves the site, to enable the researcher to recall the thoughts that are prompted by the interview. This step is also the beginning of data analysis, and so can be included in the analysis section of the thesis.

Collect secondary data
One of the principles of data collection is using multiple sources of evidences to enable triangulation. In addition to secondary data available to public, which is collected before a field visit (for example general information on the company, annual report and company profile), secondary data not available to public is also expected to be documented and to make a copy if permission is granted.

Shop floor visit
A site visit will enable the researcher to observe what happens in the field, such as how people interact, what equipment is used and the conditions of the workplace in general. Objects that can be a target of observation during a site visit include meeting, side walk activities, factory work, classrooms and the like. Unstructured questions will be asked to people that are met on location during observations. These questions are intended to clarify any evidence found during the interview, or asking about new phenomena that might arise during the site visit. Through such techniques, site visit observations are valuable in triangulating data gathered from interviews.

Closing interview and post-interview
Interviews are closed with thanks, in order to maintain a good relationship with the interviewees, and to make future contacts easier if further clarification is needed.

Phase 5 - Case study standard write up

The results from the interviews, field visits and observations are combined with information identified through desk research in order to develop a Case Study Report, which is organised as follows:

Introduction – give an overview of the case study context, with a brief description of the case companies, the products being remanufactured, main suppliers, distribution channels, technology used, and so on.

Disassembly practices in the company – discuss the practice of disassembly within the case companies in connection to organisational characteristics, process choices and product attributes.

Analysis and discussion – analyse how constructs identified in the literature as affecting disassembly are seen within the case companies. The disassembly strategies adopted by each case company are also presented, in order to identify unique patterns.

Conclusion – present the concluding remarks of the researcher.

Phase 6 - Review and validation

After the interviews, a follow up e-mail and telephone contacts is extended, in case there are any issues that need to be clarified. The results from the interviews for each case study, combined with secondary data gathered from documentations, are analysed comprehensively and final case study for each company is prepared individually.

Phase 7 – Case study analysis

Data analysis is started as soon as data collection has begun. Data analysis does not need to wait until all data has been collected. Even though there are no strict rules regarding how to analyse data, this does not mean that data analysis in qualitative research is entirely undisciplined. A five phase cycle of data analysis – compiling, disassembling, reassembling, interpreting and concluding – which is suggested by Yin (2011) will be used to analyse the qualitative data collected from case companies.

Compiling data
The compiling of data is conducted by re-reading field notes and re-listening to recorded interviews to remind the researcher about what was written in the notes. Several points must be kept in mind during the compilation stage, as follows:

1. What characteristics make the study different to others?

2. How might the data collected be relevant to the research questions proposed at the outset?

3. Are there any possibilities for new knowledge?

Continually asking the above questions during data analysis will help the researcher to achieve the research objectives.

Compiling data is not as simple as gathering the data together into the same location. The researcher needs to put the data into a consistent format, so the relationships in the data can be analysed. Equally important is that the compiled data should not include only narrative information, but also graphs, tables and other visual data formats. At this stage, developing a database is important to do before the researcher moves on to the next phase of the analytical process.

Disassembling data
Similar to compiling, this stage is also an iterative process. The researcher must go back and forth between the initial plan to disassemble data and the actual data collected. In some cases, modifications to the method of disassembling the data are required. It is not impossible that the researcher need to make some revision to the database that has been developed in the previous step.

Another important technique in this stage is coding. The researcher must assign code to words, phrases or sentences data in the database. Through coding, the researcher gains the advantage of more reliable analysis. However, some researchers point out that by not using coding, data analysis can be more thoughtful and creative, as the researcher does not have to struggle with the coding process that can be complex and time consuming. This research will use a combination of both techniques (coding and not coding) in order to gain the advantages of them both.

Reassembling data
The main purpose of this phase is to identify patterns in the data that has been disassembled. To find patterns that are relevant to the research questions, the researcher should continually ask questions such as: *How are the emerging patterns related to the proposed research questions? Do emerging patterns answer the proposed research questions? Are there new patterns, related to the research questions, that were not anticipated?*

During the reassembly of the data, several steps require attention. First, it is necessary to make *constant comparisons* across the data that has been coded. Second, the researcher must be careful with *negative instances*, patterns that appear to match, but are found not to be related after they are double checked. Third, the research must keep trying to find alternative explanations of observations; this procedure is called *rival thinking*.

Interpreting data
Yin (2011) describes interpreting as ‘giving your own meaning’ to data that has been organised. Here, interpreting is intended to provide a holistic understanding of a large amount of data in a more condensed way. The main aim of interpretation is to give an answer to *why* and *how a certain phenomenon occurs*. In addition to this, interpretation should also consider the following criteria: *completeness, fairness, empirical accuracy, value added and credibility.*

Of the five methods of interpretation described by Yin (2009), (i.e. pattern matching, explanation building, cross case analysis, time series analysis, and logic model) the first three methods are the most likely to be utilised. Interpretation will be conducted both within case analyses and cross-case, following the suggestion of Eisendhardt (1989).

Drawing conclusions
Once the interpretation phase is complete, the next process is drawing conclusion. The conclusion should logically follow from the preceding sections and, for this reason, is still a part of the analytic process. According to Yin (2011), there five ways of drawing conclusion. This study will draw conclusion using one of five methods, or a combination. First, researcher can conclude with a set of questions that indicate there is a need for further research. In this regard, the researcher concludes with ‘*what I still don’t know*’ from the current study. Second, researcher can challenge established theories with empirical findings. Such conflicting facts can be used as a starting point to draw conclusions. Comparing the results of the

study with other research using different methods is also useful when drawing conclusions. Third, researcher can propose new concepts, theories or frameworks that might contradict the present one. Fourth, researcher can draw a conclusion that makes propositions to explain the findings. Alternatively, the propositions make predictions regarding a particular facet of what is being investigated. Lastly, researcher can draw conclusion by looking at the phenomena under investigation from a broader perspective.

APPENDIX IV – Case study report

APPENDIX IVA: Case Study Report of Company A

Company overview

Company A is an independent gearbox remanufacturer based in Glasgow, which started its remanufacturing business in 1976 and it has remained a family business ever since. Given its nature of being a family business that employs a small number of staff, the atmosphere and working conditions in the company are casual and informal.

The company employs 36 members of staff, 6 of whom are allocated to the disassembly shop floor. These 6 employees do not always stay in the disassembly shop floor at all times, but can be rotated across different shop floors that need supports. The company also develops partnerships with a number of OEMs and third party logistic providers as presented in Table IVA.1.

Table IVA.1. Partner companies of Company A

No.	Customer	Type of relationship	Product
1.	Xpart/CAT Logistics (MG Rover)	After sales service provider and out of warranty period service	Automatic and manual gearboxes
2.	Nissan UK	Service exchange scheme	Automatic and manual gearboxes
3.	SsangYong	Service exchange scheme	Automatic and manual gearboxes
4.	Automatic Choice	Distributor of Company A's products	Torque converter

Remanufacturing process

In general, the process of remanufacturing in Company A is presented in Figure IVA.1 on the next page. Disassembly is an important process in solving remanufacturing problems although it cannot eliminate them entirely. Disassembly helps remanufacturers to identify problems within parts; damaged or worn out parts can be identified more easily once gearboxes have been stripped down. Nevertheless, some problems cannot be easily identified even when the parts have been dismantled. For example, a hairline crack that emerges when the transmission heats up, or the aluminium expands and lets the oil pass by, cannot be seen even when gearboxes have been disassembled.

Type of customers
The customers of Company A could be individuals, dealers or franchised garages. The company does not see cars often because most customers go to dealers, who remove the gearboxes from cars and then to be sent to Company A. Customers off the street, or from other franchised garages, send the cars to Company A to carry out the job.

Company A charges customers higher than market price. This is because the orders are in small numbers and some of them are old gearbox models. The small orders typically require customised services due to specific problems in the gearboxes. To carry out the tasks, employees need experiences that have been accumulated for a long period of time.

The company experiences different issues when remanufacturing old gearboxes. Remanufacturing these gearboxes can cost more than 500 pounds sterling. The company must buy almost all the parts that are needed during rebuild process. These gearboxes have often never been seen before by the company, and possibly will never be seen again, so they are expensive to set up.

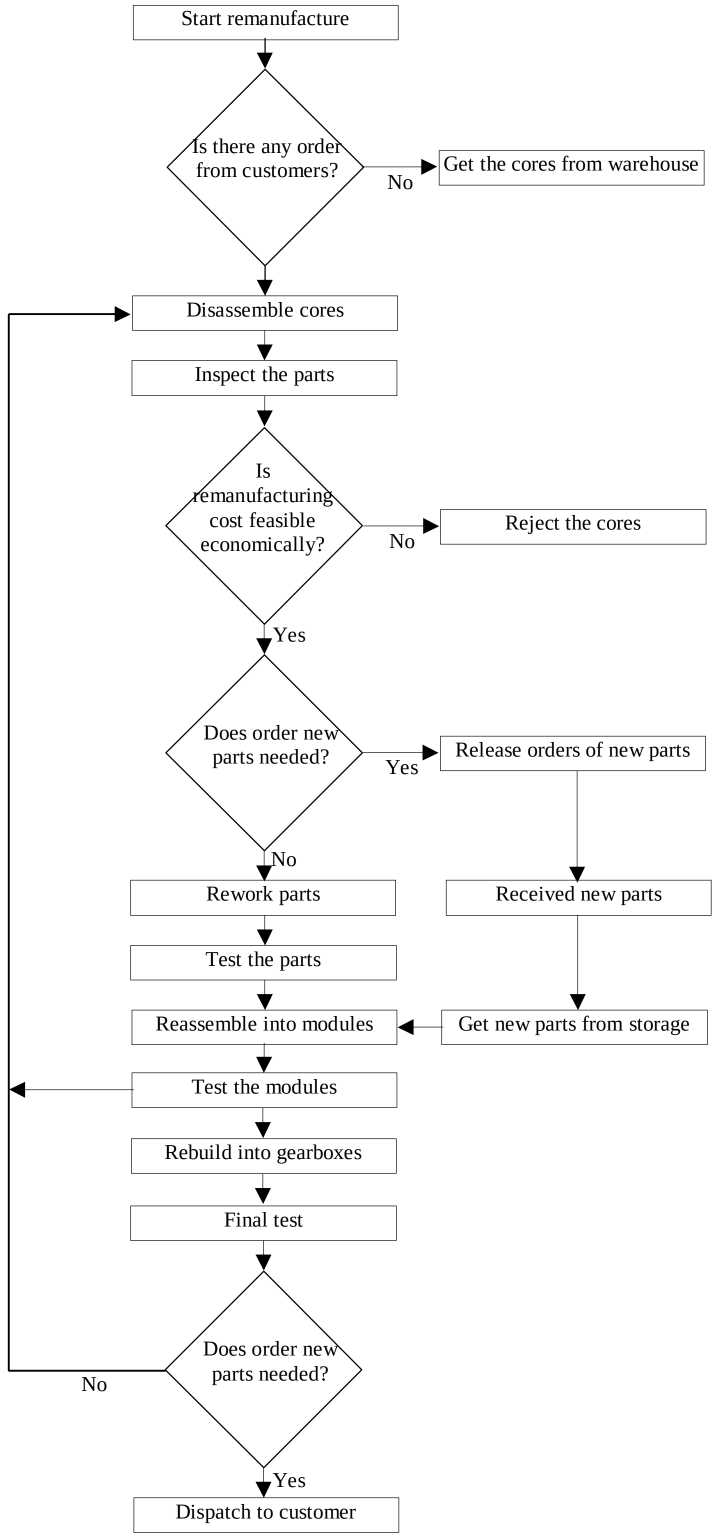


Figure IVA.1. Remanufacturing process in Company A.

Customised services for customers
Company A serves a niche market that is not targeted by OEMs remanufacturers. For example, the company target customers that require remanufactured gearboxes produced 50 years ago. The number of customers requiring these gearboxes is very rare, and so OEMs are not interested in this market segment. The new components, which are needed in product rebuild in remanufacturing, are no longer available either. Thus, this niche market becomes the target for the company.

Facility for disassembly process
Company A uses a common area, tools and equipment to disassemble various types of cores, and a shared facility to disassemble various types of cores. The tools for disassembly and equipment for handling and moving the components post-physical disassembly activities are located within the facility. The resulting components of physical disassembly activities are placed in an area that is used for all cores types. However, in some cases, the company has to buy a new tool that is required to process a core only. In the future, there will be no similar cores or cores that need that tool again.

Remanufacturing of old product models
The major problems that emerge during remanufacturing are due to new components availability, particularly for old product models. As an example, when this study was conducted, Company A was remanufacturing Mercedes that were made in 1968. It is very difficult to obtain new parts for classic cars, and therefore disassembly is a critical process in recovering the parts, as otherwise, the company has to make the parts themselves, or buying new ones at an extremely high price. When it comes to setting up the gearbox, the overall cost could reach hundreds of pounds.

Organisational characteristics

Service exchange scheme
A number of OEMs used to work with Company A, including Automatic Choice, Xpart/CAT Logistics (MG Rover), Chevrolet, Daewoo, Nissan UK, SsangYong, Subaru, etc. Currently, there is only Hyundai that still maintain this relationship with the company. The company is a dealer for Hyundai customers whose products are still under warranty period. If there is any problem with the products, these customers do not contact Hyundai. They instead contact Company A and the company offers its services on behalf of Hyundai.

The guarantee that Company A offers to Hyundai is specified in a contract. Hyundai that offers 5-year guarantee build up cooperation with the company to cut costs. If the transmission from Hyundai fails when the car is one-week-old, the guarantee from the company has to cover it for 4 years and 51 weeks. But, if the transmission fails in the last week of the five-year period, it has to guarantee it for a week. So the warranty exists just to get the products out of their warranty period.

In addition to developing cooperation with OEMs, the company also offers services to franchise garages, distributors or independent garages in the UK and Europe. Despite the historical success of this cooperation, most of the productions demanded by customers who come directly from the market. For these customers, the company offers 3 years guarantee.

Knowledge transfer from OEM
Although Company A has a number of relationships with OEMs, the company does not receive any support from them. The company acquires the knowledge for disassembly from the information that is available to the public. In addition, Company A carries out reverse engineering to the gearboxes, by dismantling them, learning how they work and then reassembling them. One of the managers admitted that this method is an expensive process, but there is no other way.

The company is confident that it can compete with OEMs because no company possesses all the product knowledge, even OEMs. For example, ZF makes the electronic components but Bosch carries out the programming of the components. Therefore, the knowledge of the two companies complements each other.

Cores sorting

The company does not organise cores sorting before these cores are disassembled. As a result, most of incoming cores are disassembled. Some cores are rejected during the disassembly process and are not processed further because there are too many damaged components that cause remanufacture not economically feasible. Cores that are not rejected are not always profitable. Most of them make profit while others make lost but the overall process is still profitable.

Cores from customers are usually accompanied with a logbook or product orders that explain what should be done with the cores. The logbook is useful as it gives an early indication of what the extent of the problem is, and also what necessary action can be taken early – e.g. ordering the necessary components.

Cores rejection
Despite the company does not organise cores sorting, it is still possible that a core is rejected. It should look at two points of view before rejecting or accepting the cores. From a financial point of view, everything that it spends on remanufacturing is recorded on a computer system. When the cost of a job reaches a certain level, an alert flashes up on the screen that says it is no longer economically viable. Some transmissions might cost £1,200 pound to remanufacture and so the company will not make money from processing them.

Scrapping excess cores
Company A feels it takes a bit of a gamble when it comes to deciding on the appropriate number of products. The company sometimes buys 200 cores but then there is insufficient demand for these products. The company then has to scrap or sell some of the products to other parties. If it seems there will be future demand, the cores will be disassembled, remanufactured and the remanufactured gearboxes are put in the warehouse. But, if it is unlikely there will be demand in the future, the company has to scrap the cores. The manager admitted that this is a costly decision, but when it happens they have no other option.

Product information database
The company uses labels to support the product information database. Product labelling is available to support the procurement, replacement and reassembly of parts; but it is not used for supporting product disassembly. In future, if the products are returned, the company can identify exactly what new components fitted to the transmission, who did it, who rebuilt it, who tested it and when it was sold. However, it is very rare that the company will see the same cores again in the future.

Suppliers of new parts
Procurement of new parts takes 1 or 2 days, but if it is difficult it can take up to 10 days. The suppliers of new components suppliers are from many countries, such as the US, Germany, Korea and the UK, but Hyundai prefers Korea, as the suppliers from this country offer a significantly lower price. For classic gearbox models, the waiting time can be longer. In some cases, the company has to make the component in-house because there is not any vendor who can supply the parts.

Process choices

Multi-skilled employees
The manager of Company A stated that companies employing less than 25 workers would be more efficient if they employ multi-skilled employees while those that have 50 or more employees would definitely be more economically beneficial to use specialised people. He further explained that his company is at the top level end of having multi-skilled workers because it employs 25 employees. He explained that employing multi-skilled employees is not an ideal condition, but the alternative of developing specific skills would be more costly.

Disassembly process does not require specific skills. However, it does not mean that anyone can do the job. The job requires understanding regarding standard of new product specifications, how the gearbox works and a long time experience. The experience is needed to ensure that the employees can solve a wide variety of problems from incoming cores.

The company does not organise formal training for new employees. Rather, its training is organised informally by the use of job shadowing. New employees work on a job next to a senior employee, doing the same work as him. The senior employee gives the new employee instructions and then provides feedback as to how they are doing. The training is not structured, as it is embedded in the new employees' daily routines. There are 6 employees that are related to disassembly jobs, who can switch jobs very easily. The rotation of multi-skilled employees is part of the company strategy's to reduce idle capacity.

General tools and equipment

The company generally uses tools and equipment that can be obtained from the market. Due to the general nature of this equipment, some of it needs modifying to meet the company's specific needs, and only a small proportion of the equipment is designed in-house. The company relies on publicly available information to obtain the product specifications without any assistance from OEMs. The internet is the main source of information, and sometimes the company buys guidance from a product manual.

As mentioned previously, although disassembly process needs general tools and equipment, not everyone can do disassembly. Ability to choose appropriate tools is one of critical success factors. In addition, ability to identify specific sequence for different models of gearboxes needs a long time working experience. On average, staffs working in the company have been with carrying out their job for 15 years.

Flexible production schedule

The production schedule is very flexible and depends on what is happening in the company. One of the supervisors explained:

'It really depends on what's going on. Things can change daily. I could take tomorrow off and say to the guys tonight this is what's to be done tomorrow'.

Employee skills development

A formal education background is not required in order to be qualified to work in the company but the candidate must be eager to learn new things. This due to the fact that most of the jobs in the company are learnt by the employee actually doing them. The director explained that he preferred a candidate who does not have much previous experience. For example, candidates that have backgrounds as motor mechanics are not preferred as they could pick up bad habits during whilst doing their previous jobs. As employees develop their skills from the experience they develop on the job, the company provides no formal training. All employees learn and acquire their skills with the assistance of colleagues.

Mixture of make-to-order (MTO) and make-to-stock (MTS)

The company adopts a mixture of MTO and MTS, with the former is more dominant than the latter. The orders come from individual customers, and the timing of these orders is uncertain. The volume is low and the service customised. Given the characteristics of these orders, the company should be responsive to customers' demands, regardless of the volume of the orders.

The company holds a stock of various gearbox models, as many as 5,000 at any one time, which are all ready to be delivered to customers. There is also a large amount of cores in stock that are ready to be remanufactured. This indicates that the company develops stocks of cores as raw materials to minimise idle capacity.

When Company A does not have orders, it builds up stock of remanufactured gearboxes to replace those that have been sold in the last six months. The company needs to ensure that it has at least a four or five months' stock of gearboxes. The director of the company admits that keeping a large number of inventories is costly, but he argues that there is no other way.

Volume of cores supplies

Cores arrive at the company's facility in different volumes and models. They can come from franchised garages, core brokers, individual customers or manufacturers. In the case the company wants to obtain cores from remanufacturers, it will buy as many as 5000. This figure is too many for the company, so it has to share them with other remanufacturers.

Different customers have different behaviours. Franchised garages send the cores to Company A when they have problems with the gearboxes on customers' cars; these cores are usually in low volumes. Companies like Hyundai, Sprinter and Chevrolet send two or three transmissions to the company a week. Therefore, the volume of incoming cores varies from one day to the next and the vehicles that come into the workshop are different models and brands, and in different conditions.

Product attributes

Stable residual value of gearboxes
The value of cores remains relatively stable over time. In fact, a transmission can stay in the warehouse for three years or more without any value depreciation. The company is not concerned about the depreciation in value, but the uncertainty pertaining to customer demand. Due to this reason, the company has to watch what they stock in the warehouse and what models commonly demanded by customers.

Varying recovery rate of gearboxes
The recovery rates of gearboxes vary, depending on the quality of the cores. According to a supervisor in the company, the recovery rate could be about 75 per cent, but this figure is not fixed. For instance, when the company remanufactures 20 gearboxes, it can produce a 75 per cent turnaround on that. But when the company intends to produce 20 gearboxes, they will take 30 cores from the warehouse, which means it has only recovery rates of around 66 per cent.

Mandatory disassembly
There are mandatory part replacements that result in mandatory disassembly. To do this, the company makes a list of the parts that always need to be replaced, as they are automatically thrown away in the remanufacturing process. Most of the parts are wearable soft parts, such as the seals, bearings and friction plates.

Flexibility required to respond to innovation and market needs
As a small company, Company A can adapt to external conditions easily, like adjusting to market conditions and the strategy of OEMs. An introduction of new products is not a threat to this company and the introduction of a new product model can even lead to opportunities. When the OEMs launch new products, the company needs six to eight weeks to up-design its resources and remanufacture the new product models.

Level, sequence and procedure of disassembly
Documents that provide a general procedure for remanufacturing is available, but it is not for disassembly process. Regarding the procedure for disassembly, the supervisor explained, *'If you want to disassemble, just do it'*. Therefore, the employees are given the room and flexibility to disassemble cores and, for this reason, disassembly might not always be carried out in the most efficient sequence.

Type of materials
The materials that make up a gearbox are relatively homogenous. They are predominantly made from steel iron, aluminium, brass, etc. The components made from softer materials, such as gaskets, seals, bearings or friction plates, can be disassembled in a destructive way because they have to be replaced. This destructive method means disassembly can be done quicker.

Number of components
The number of components in a gearbox can vary between 150-200, depending on the model, the manufacturer, the year of production and its number of speeds. For example, the average number of components for a 5-speed transmission would be roughly 180. This figure would increase slightly if parts, such as the rings, nuts and bolts, are added.

Adoption of ecodesign principles

It seems that OEMs have adopted ecodesign for gearboxes from time to time. Nevertheless, this adoption does not always provide remanufacturers with advantages. In some circumstances, the use of ecodesign principles can even hinder the remanufacturing process. For example, using less material is a technique that is employed to reduce waste at the end of the product's life, but could actually have a reverse effect on remanufacturing.

APPENDIX IVB: Case Study Report of Company B

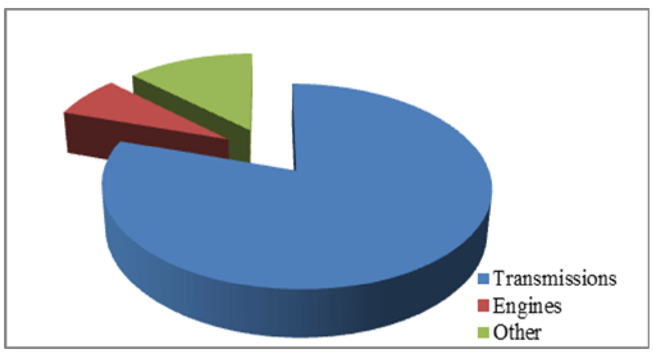
Company background

Company B is a contract remanufacturer established in 1960 and situated in North Somerset, England. The business of the company is predominantly gearbox remanufacturing, which accounts for 75% of the operation, while engine remanufacturing and other activities, make up 12% and 13% respectively.

Company B company has 75 employees with different skill sets and levels of expertise. The company produces about 18,000 remanufactured products, which resulted in a £7 million turnover in 2012. Considering the amount of turnover and the number of employees, Company B is categorised as a medium-sized enterprise, according to the Department for Business Innovation & Skills (2007).

In Company B, having a high number of cores in stock is one of the strategies that have been used to ensure that production keeps running smoothly without any interruptions due to a lack of raw materials. Given that company B remanufactures cores that are readily available in the warehouse, the remanufactured products dispatched to customers are not the same as the cores that are received from them.

The company obtained licences for quality in remanufacturing, such as TS16949:2002 (which is the most important certification for any company in automotive remanufacturing) and ISO 14001. It also received the Volvo remanufacturing programme award in 2007. Key facts about the company are presented in Figure IVB.1 and the process of remanufacturing is depicted in Figure IVB.2.



Product Mix by Value £ Transmissions 75%
Engines 12%
Others 13%

Employees currently75
Turnover £7m

Figure IVB.1. Key facts of Company B

(Source: Company profile presentation)

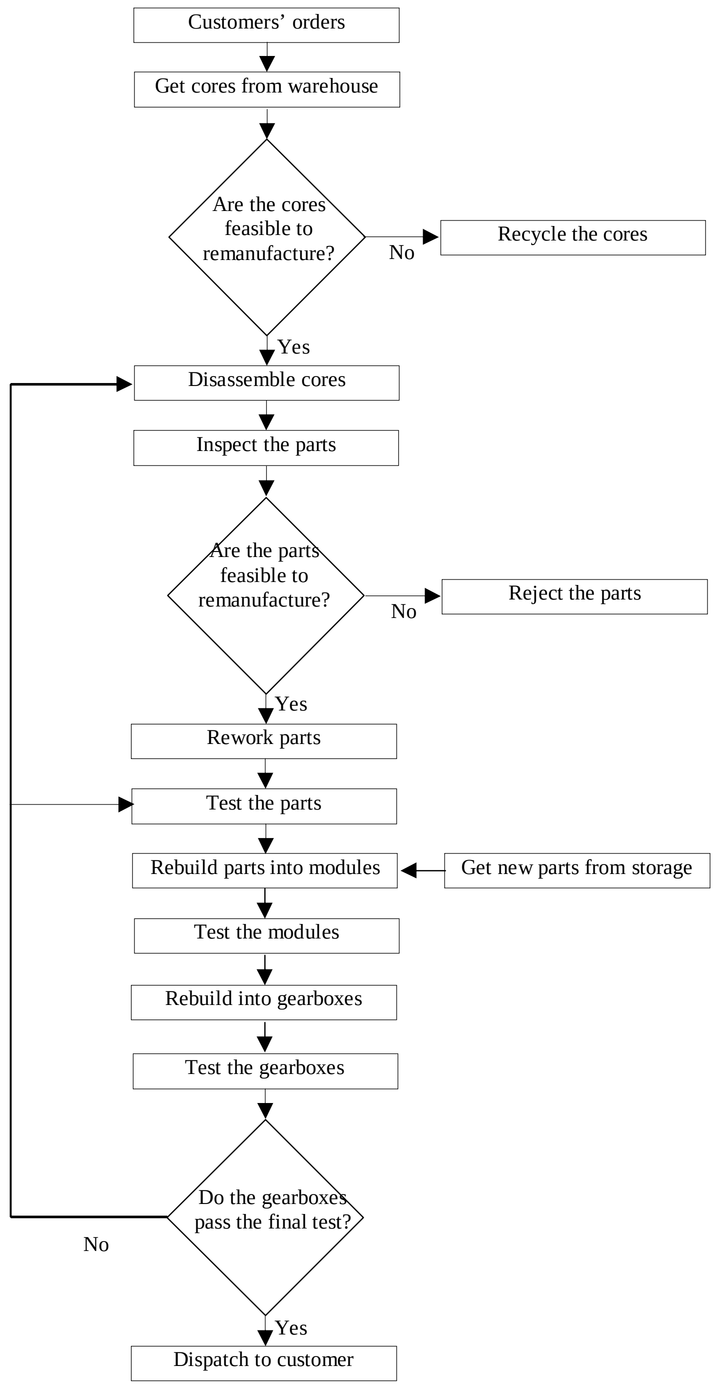


Figure IVB.2. Process of gearboxes remanufacturing in Company B

Organisational characteristics

Knowledge transfer from OEMs

The company cooperates with OEMs to develop its remanufacturing facility. The customers, which are OEMs, have their own performance specification of the final products. The remanufactured products must achieve the same standard that is set up by OEMs. To attain this, the company works together with engineers from OEMs to ensure the output of the company's remanufacturing process complies with those performance requirements.

Relationship with OEMs

The relationship between Company B and the customers is a stock-based one. Customers order remanufactured products from Company B and the company processes cores that are readily available in the warehouses and then dispatches the remanufactured products to customers afterwards.

OEMs retain ownership of the cores until they have been remanufactured and sent to customers. Under this scheme, OEMs, as the customers, are required to pay the rental cost for the warehouse, which is managed by the company. The company does not have any concern about how long the cores will be in the warehouse, as the burden of the holding cost belongs to the OEMs.

Cores acquisition

Company B obtains cores from its OEM customers, as well as cores from different customers (e.g. Ford, Audi, Jaguar and Land Rover), which arrive at the company almost every day. The OEMs manage reverse logistics networks to collect products after they have been used by customers. During the collection process, the cores are sorted by the dealers and OEMs. Cores that can produce profit only that are selected and redistributed through reverse logistics networks. Communications with OEMs and up-to-date forecasting regarding the number of cores arrival, which is carried out periodically to adjust to current conditions, are critical strategies for Company B.

Research and development for disassembly

Company B manages a research and development (R&D) team who is responsible for carrying out research. The research related to disassembly is undertaken just after the launch of new products by the OEMs. The time gap between the start of the remanufacturing program – i.e. signing of the contract with OEMs – and the arrival of product returns from customers can be any period between 6 to 12 months so that Company B has a sufficient time for preparation.

Disassembly procedures

The R&D team is also responsible for preparing formal disassembly procedures, such as employee training, guidance for disassembly and the design of equipment used to support disassembly. All the procedures used to remanufacture cores are designed at the beginning of the program. During the research and development stage, the team writes the remanufacturing specifications, which includes a procedure that explains how to disassemble, which parts should undergo more detailed inspection and what skills necessary for the tasks, etc.

Cores sorting

The cores are sorted into three phases before they undergo disassembly. The first is when the cores arrive at the dealers' facility; the second is when they are received by OEMs and the last is when they are sorted at the company's warehouse, just before being moved to the disassembly facility. The second phase is carried out because OEMs have their own standards, which can be tighter than those of the dealers. During the last phase, the cores are classified into different groups. The classification is needed because the cores have been in the facility for some time, which can result in deterioration or obsolescence. Such a method can avoid unnecessary costs that occur because of disassembling low quality cores.

Product information data base

Company B manages a product information database, which supports remanufacturing and disassembly in particular. Every remanufactured product is attached with a numbered label and then entered into the database. Using the database, the company can identify gearboxes that have been remanufactured and then returned to the company. For example, the company can identify gearboxes that were remanufactured fifteen years ago. It also enables the company to identify the parts that have been replaced, who replaced them and when they were replaced. The database is also used to manage production planning and to evaluate the performance of the company, in terms of costs, material control and the inventory.

Process choices

Tools and equipment
The equipment for remanufacturing is customised for different processes in remanufacturing. For example, crates that are used for moving and handling components just after the gearboxes have been disassembled are different from crates used for the cleaning process. There are differences in the crates for different products models as well.

Different product models require separate facilities for disassembly. Whenever the company remanufactures various product models, different employees will come to different bays. One of the respondents stated that, *'Moving employees is much easier rather than moving tools and equipment.'*

Developing customised tools and equipment at the beginning of the remanufacturing program is a challenge for the company. It has to spend money on investment to carry out the research, set up a facility and develop training materials, etc. The amount of investment to set up a facility to disassemble a gearbox model can rise to £3,000, but this figure will be spread over about a 5-year production period.

Made-to-order production system
Cores are obtained from OEMs – which also act as customers – through contractual agreements and stored in a 30,000 square meter warehouse facility, which holds stocks of up to 20,000 cores at any one time. This is equivalent to more than one year's volume of production. Some of the cores could be in the warehouse for 10 years. For this reason, the company organises cores sorting to ensure that only cores which can meet economic feasibility criteria that will be remanufactured.

The volume of cores that are supplied to the company is affected by a number of factors. A peak period occurs around the holiday season, when many people have just come back from holiday. Then, just after that, the volume of production returns back to normal. In the beginning of the remanufacturing program, a point when the company signs an agreement with customers, there is a low volume of cores and then it increases gradually.

Volume of production and the production schedule
Despite the fact that the company always has cores in the warehouse, there can still be problems because some critical components are not always available. So the company never has a 100 per cent production capacity at any one time. The company does not start the production process until it ensures that all the necessary components are available for the rebuilding of the products.

Company B attempts to minimise idle capacity by adopting a robust production schedule. This is intended to streamline the flow of work, so that the disassembly runs smoothly and efficiently. To support this robust schedule, the company builds stocks for components that are used for mandatory replacements during the gearbox rebuilding process. To make disassembly run quicker, typical problems in gearboxes are identified. Also, some components that typically cause problems have been identified and are disassembled destructively.

To support high production volume, the factory is designed much like production lines that use a high volume lot size. The cores flow in the line from one shop floor to another. Once the cores have been disassembled and the components have been put in the customised crates, they are moved to other shop floors using this line. Production in high volume lot sizes is preferred, rather than in units, to reduce fixed cost.

Employee skills
Resource sharing occurs between different processes in remanufacturing. The skills of the employees are organised in the 3-1-3 scheme. In this scheme, an employee should have at three skills; and there should

be at least three employees capable of doing a job. This gives the company some flexibility to carry out job rotation. The employees can be rotated to different positions while the tools and equipment remain in the same place.

Before an employee is qualified to carry out disassembly, he must first attend training for several weeks or months. The skill of the employees increases as they gain experience and obtain daily support from quality engineers. While performing disassembly, the employees are guided with formal documents about the disassembly sequence, as well as tools and equipment.

Reassembly
Once the gearboxes have disassembled, the components are reassembled into the same gearbox. This procedure is not compulsory, but it is easier for the company to do this. In addition, the resulting products have a better performance compared to those reassembled by using components from different gearboxes. For this reason, disassembled components from a gearbox are located in the same crate.

Product attributes

Mandatory replacement and compulory disassembly
There are some components that are always be replaced regardless of their condition, like bearings and gaskets. Due to this mandatory replacement, the company must always have sufficient stocks of these components. To manage the parts inventory, the company attempts to keep this at a minimum level, although it is sometimes overstocked as it has to buy a minimum order quantity from suppliers.

Number of components and type of materials
There is a speculation due to uncertainty about the number of orders for new components. The company manages more than 3,000 products, but only 500 products that are currently active for remanufacturing. In a gearbox, there are roughly 200 components, depending on the model, speed, brand and several other factors. The number of components needed to build remanufactured products cannot be identified until the cores are disassembled. The materials used to make gearboxes are relatively homogenous and mostly consist of metal with a minor amount of other materials, like magnesium, rubber and plastics.

Gearbox is functional product
Gearboxes are functional products that have long life and their value is relatively constant over time. Although Company B remanufactures a high number of diversified product models, a high volume of production helps the company to keep the cost down.

There are regulations that require OEMs to support customers by providing components for the products within 15 years. During this period, gearboxes can come back to the company many times. After 15 years, there is no longer support from OEMs and, as a result, the company can no longer remanufacture due to the lack of new parts. One of the alternatives to this situation is to carry out core cannibalisations.

Cost of gearbox remanufacturing
Company B manages remanufacturing costs by using estimation. The cost of remanufacturing is based on estimation by using batch samples that consist of 30 units. Due to this estimation, there is a variation between batches. For example, the cost for the current batch is £60 pounds, but for the next batch it is roughly £100.

The cost of remanufacturing mainly consists of expense of labour and new components. For labour, the company measures how long the remanufacturing process takes. A typical gearbox usually requires three hours working time, from the beginning to end, but in actual practice it might need two days. Regarding the new components, some OEMs supply Company B with the parts that are needed during the product rebuild, but other components are obtained from non-OEM suppliers. These suppliers should be approved by OEMs before they start working with Company B. All components acquired from these suppliers are tracked down to see how much has been spent on each product.

Sequence of disassembly

A research and development team has prepared a sequence of disassembly in advance to be followed by employees during the disassembly process. Although it might be possible to carry out disassembly by using a different sequence, the team prepares the sequence that is recommended to employees. All products are disassembled completely due to the need to carry out several processes on the components, such as cleaning, testing and remachining.

Ecodesign principles

There are extremely few products that are designed for disassembly. These are all built with robot assembly and the design is intended to support assembly, not disassembly. Some of the components should be disassembled by using a circle of metal, a big washer, welded on to the bearings and operated by two employees. This process of separating the components costs the company £1.5 per transmission, which is a very large amount over the course of a year.

To address this issue, Company B provides feedback to OEMs. This is based on its experience in remanufacturing their products. Of particular concern is how to improve the remanufacturability of the products and their disassemblability. This is one of the main concerns, as most products are not designed for remanufacturing, so that the recovered value cannot be optimised.

There has been a requirement that the OEMs should use standard components, but it seems this has been ignored. It might only be a bolt, where a standard bolt is 100 millimetres wide by 1.5 millimetres, but the manufacturers decided to use 102 mm and 1.70 mm. The standardisation helps remanufacturers to carry out the disassembly, but it hinders manufacturers who seek for product innovation.

The adoption of ecodesign principles does not always make the remanufacturing process easier. Some of the gearboxes are more sensitive than they used to be. The gearboxes need more care during the remanufacturing process because the thickness of the wall has been reduced.

APPENDIX IVC: Case Study Report of Company C

Company C is part of a global holding company that covers a wide range of businesses and operations and has operated remanufacturing services since 1973. Company C, located in Rushden, Cambridgeshire, is one out of two branches remanufacturing services in the UK. The other one is based in Shrewsbury, which is also the head office for the Europe. The branch in Rushden that employees 103 skilled and semi-skilled employees used to be under the name of Wealdstone Engineering which was then acquired by the Company C's holding company as part of its expansion to offer remanufacturing services in the UK.

In terms of the type of remanufacturers, the company can be classified into three types of remanufacturers: an OEM remanufacturer that remanufactures its own engines and equipments, a contract remanufacturer that offer third-party services to automotive OEMs, and an independent remanufacturer that remanufacture some components. In this study, the unit of analysis from this company is automotive engines and considers Company C as a contract remanufacturer. This is due to the fact that the volume of automotive engines remanufactured in this company is much higher compared to other product types with production volume of 4,172 remanufactured engines in 2010. Overall, during the year the company generated turnover as much as 17.83 million pound sterling. The company serves 26 automotive OEMs including Aston Martin, Mercedes Bens, Audi, Ford, and Land Rover, to name a few. The process of remanufacturing in Company C is presented graphically in Figure IVC.1 on the next page.

Organisational characteristics

Relationship with OEMs
As a contract remanufacturer, Company C buys cores mainly from industrial customers, which are OEMs. Then, the cores are sold back to the customers after they have been remanufactured. In addition to this, the company also obtains some cores from dealers. The contract varies from 3-11 years and can be extended subject to agreement with the customers.

Knowledge transfer from OEMs
The company obtains knowledge regarding know-how to undertake remanufacturing from the OEMs, except for some brands, namely Land Rover and BMW. The supports include how to set up the facility, how to train employees and how to set up testing standard for the final products, etc. The OEMs have interest in providing the supports since these ensure that the final remanufactured products have the same standard as the new-ones. However, despite the company signs the contracts with the OEMs, obtaining information and awareness from the OEMs is not always easy.

Size of the remanufacturer
OEMs seem to hesitate investing their resources and developing relationships with small companies. This is the reason why most independent remanufacturers are predominantly SMEs. From the perspective of the remanufacturers, larger size companies allow for standardisation in remanufacturing process. Bigger companies typically have better resources to meet manufacturing operations standard set up by OEMs in comparison to smaller companies.

Cores sorting
The company organises cores sorting which is organised in two levels. The first is when the engines are taken from the vehicles, which happens at the dealer's facility before the cores are taken back by the OEMs. The second is at the company's facility just before the cores are disassembled into components and classified into component families. At this stage, the sorting is conducted at a more detailed level in order to examine the condition of components before they are disassembled.

Sorting is useful for disassembly in several ways. It identifies low quality cores which are to be recycled and are not necessary to disassemble. Therefore, the company can avoid costly operations by rejecting cores that are not necessary to be disassembled. Furthermore, one can determine which components are to be recovered and hence, pull out the only desired ones.

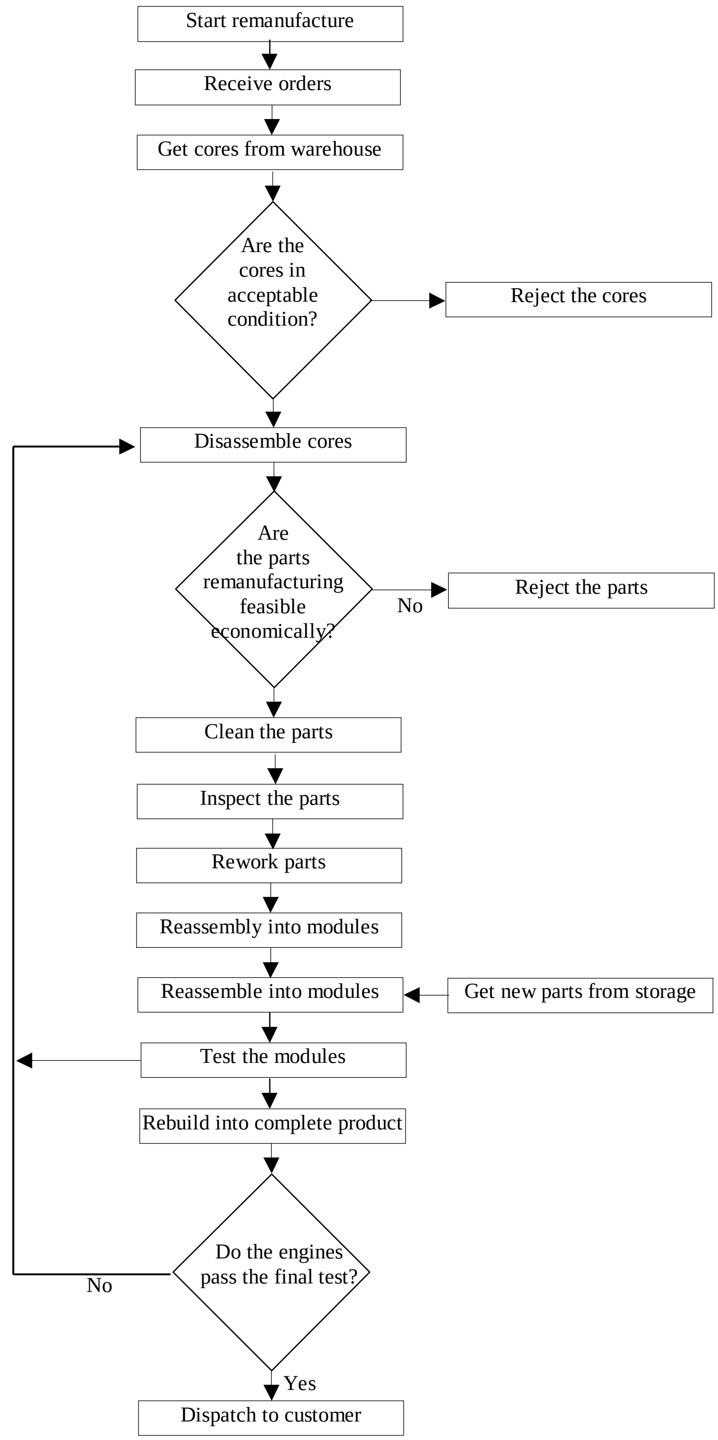


Figure IVC.1. Remanufacturing process in Company C

Product information data base
It seems that Company C relies on information gathered from cores sorting in its facility just before the cores are disassembled. It could have been more beneficial for Company C if the OEMs or the dealers who carry out previous core sorting forwarded the databases containing the sorting information to the company. The OEMs and the dealers seem to keep the data and information for themselves, and do not want to share this with other parties.

Process choices

Made-to-Order production system
In general, Company C predominantly adopts MTO system with a job shop layout and uses separate dedicated areas for different processes. Once the orders have been received, production schedules can be arranged including allocation of resources for disassembly. Tools and equipment for disassembly are located in fixed areas so that the employees need to come over to these locations. To support MTO, the company conduct joint forecasting with the OEMs. This strategy is used to minimise idle capacity and enable the disassembly shop floor to operate in an efficient way.

Volume of cores supply
Before Company C company signs contracts with its customers, it is important for the company to ensure that the required resources are available including tools, equipment, employee skills, and qualifications. Then, they can translate the requirements from the customers into operations strategies of the remanufacturing. This is due to the fact that most of the works from customers are unique so that managing the voice of the customer is of high importance.

Volume of cores supply affects the decision of the company to accept or reject the remanufacturing contracts. The company also needs to review regularly the economic feasibility of remanufacturing operations, considering the volume of supply typically increases and decreases from time to time during the contracts.

Tools and equipment to disassemble
Company C invests a large amount of its financial resource to develop disassembly facility. The investment covers spending to develop tools in-house, employee training, and developing formal procedures for disassembly. The factory organises its facility using a cellular design and a dedicated shop floor for disassembly. These are all intended to streamline the disassembly process.

Production levelling
The company utilises production levelling to distribute production evenly across different periods. Reducing idle capacity is important since the company spends a large amount of fixed cost investment to set up the facility.

The company maintains stock of cores at a certain level during the contract periods**.** Finished products will be dispatched as soon as they have been completed. Stocks are available at almost every stage of remanufacturing process as part of production levelling strategy.

Employee skills
The skills needed to carry out remanufacture are arranged in a 3-1-3 scheme so that the employees have some degree of specialisation. In this scheme, employees who are assigned to carry out disassembly tasks also possess skills to carry out other jobs. As such, idle capacity can be avoided and therefore more optimum employee allocation is resulted. If the employees are not available, employees from other departments can be allocated to the disassembly shop floor to substitute disassembly shop floor workers.

The company combines a formal training with peer coaching to develop employee skills. Before the employees are eligible to carry out the disassembly tasks, they have to undergo formal training, then work to serve somebody, do the same job alongside somebody else, do the job but under supervision of a more senior employee, and finally become eligible to perform the job independently.

Product attributes

Value of recovered products

Automotive products remanufactured in Company C have relatively stable value over time. The products in this company can be remanufactured up to 2 or 3 times with the same quality as the new ones.

Sequence and level of disassembly

A team of R&D carries out research to identify the sequence of the most efficient disassembly. Employees should follow this sequence and they do not need to find the sequence by themselves. The cores are disassembled into sub-assemblies which thereafter are moved to different areas for further disassembly. Once the sub-assemblies are moved to different areas, further disassemblies are conducted. The cores are disassembled completely until all the components are separated. This complete disassembly is one of prerequisites in order other processes in remanufacturing (i.e. cleaning, testing, inspection) can be carried out.

Type of materials

Automotive engines do not have a wide variety of materials because it is largely made of metal based materials. As such, all the components require homogenous treatment and there is not any specific treatment required due to its sensitivity (i.e. cannot be touched, need certain temperature, heating etc.). The materials include iron based alloys such as structural steels, stainless steels, iron based sintered metals, and cast iron. Other materials are like aluminium alloys are also used for piston, cylinder head and cylinder block. Some minor components like bearings are made of rubber that is prone to damage as it is not as robust as metal based materials.

Number of components

Automotive engines that have a higher number of components require more works to disassemble. This is due to the fact that disassembly is mostly consisting of disconnecting joints. The more complex engine structure, which is indicated by the number of components, the more specific the sequence of the disassembly.

Ecodesign principles

The adoption of ecodesign principles seems very limited so as to complicate disassembly. OEMs very rare consider ecodesign to support remanufacture during new product development. This condition is indicated by the high number of product variants. Once the products have been disassembled, they need to be classified by further details. This condition requires the company to prepare more equipment.

APPENDIX IVD: Case Study Report of Company D

Company D is a subsidiary of Xerox, a global photocopier company, that was acquired in 2011. The company is one of nine service providers in the UK that offer digital document solutions and has run a remanufacturing business since 1994. The company office is in Glasgow that also responsible for another facility located in Aberdeen.

The company is supported by its own reverse logistics team that collects cores from customers and distributes remanufactured photocopiers. Its customers, who are mostly industrial, have developed a relationship with Company D based on a leasing agreement. With the support of 43 employees, the company delivers approximately 40 remanufactured photocopiers per month from a wide range of models.

Remanufacture can be carried out to recover as much as 70%-90% of the machine components. These are then rebuilt as new products or upgraded into newer product generations. The rest of the components, which are not qualified for further processes in remanufacturing, are sent for disposal (e.g. PWB, batteries, lamp) or are recycled (e.g. plastics, copper wire).

Remanufacturing process

Once the cores have been moved to the disassembly shop floor, the disassembly process begins. Disassembly in photocopiers occurs at a high degree, almost at full disassembly. At the first stage, panels are removed from the machine, which is then cleaned, tested and repaired if necessary. Major modules, such as the image-processing unit, paper feeder, transport unit, duplex unit, etc, are disassembled from the main body of the machine.

Afterwards, the subassemblies are moved to a small parts stripping process. The smaller parts are then moved to the next process, which is cleaning and painting. Cleaning is carried out by using three methods: manually by hand, using solvents, and using carbon dioxide blasting technology. The last method produces better results compared to others as it produces less hazardous waste, reduces cleaning times and increases the recovery rates.

Next, the sub-assemblies are repaired, if necessary. They are also repainted to restore the physical appearance of the products. The mainframe of the machine is cleaned by using air-gun dust, before it is cleaned manually by hand. The other main sub-assemblies follow the same procedures as the mainframe.

The final phase of remanufacturing is reassembling. At this stage, all the units are rebuilt and then undergo a series of tests to ensure that the machine runs properly. Necessary adjustments are also carried out to correct any deviation that is found. Lastly, cosmetic checks are made to ensure that the products look as good as new. The process of remanufacturing in Company D is presented graphically in Figure IVD.1.

Organisational characteristics

Relationship with OEMs

Company D is an OEM remanufacturer, as it is a subsidiary of an OEM specialising in remanufacturing operations. All the cores supplies are obtained from customers who sign leasing agreements with the company, which are based on pay-per-copy. In this agreement, the company retains the machine ownership and ensures that the equipment is in good working condition.

Cores arrive at the facility in a more predictable manner because the circulation of photocopiers forms a closed-loop chain. The forecast of cores arrival is carried out by looking at historical data available in the company.

The company also offers part upgrades during the lease agreement, which means customers can ask for a photocopier upgrade halfway through the lease agreement. Both parties then prepare a new contractual agreement based on this upgrade. In this scheme, the company has a full record of the machine's history, which can help it to maintain the photocopiers, upgrade them again and remanufacture them. This scheme saves the customers money, as they do not have to buy an entirely new photocopier.

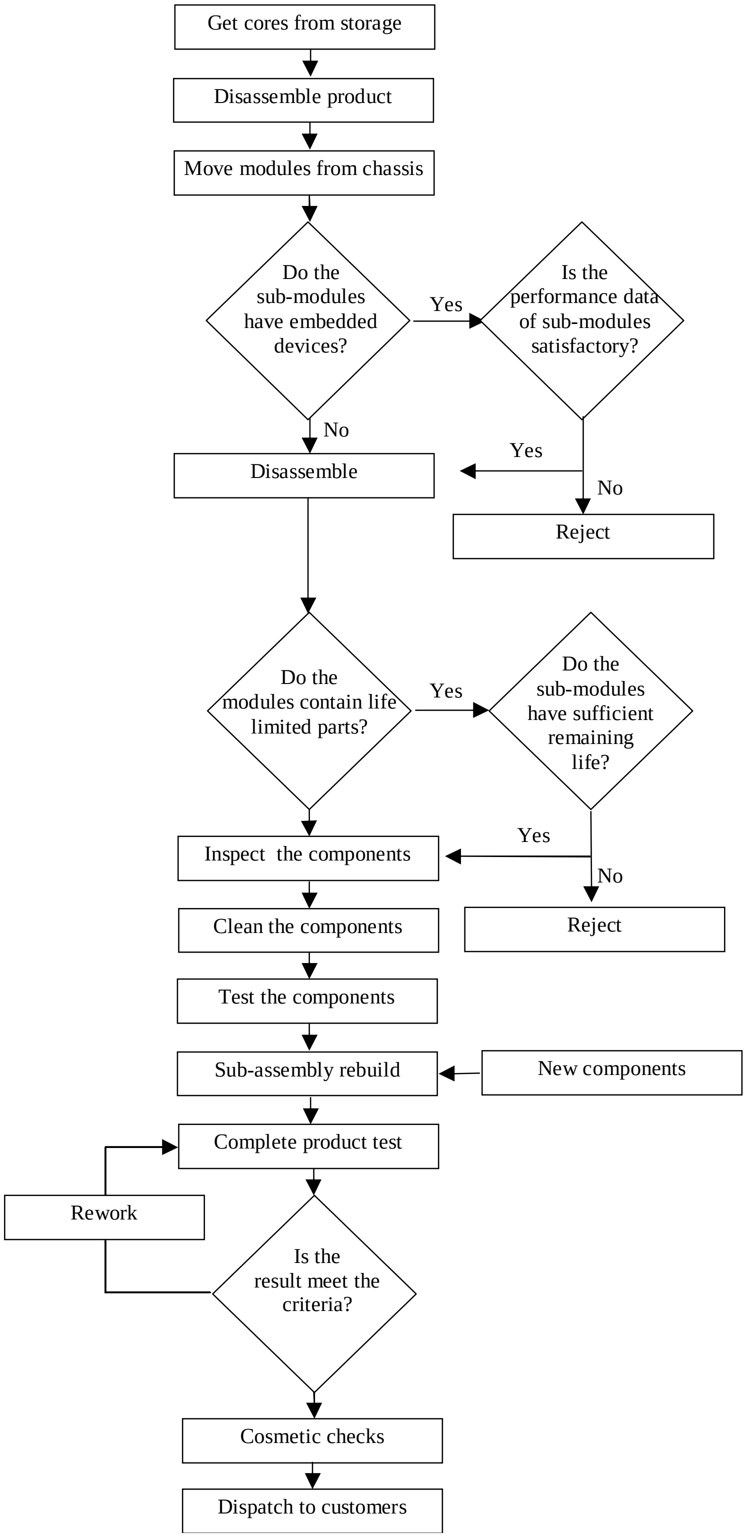


Figure IVD.1. Remanufacturing process of photocopiers in Company D

Knowledge transfer from OEMs
Company D receives knowledge transfer from its parent company regarding product specifications. In return, Company D provides feedback to its parent company about the performance of the products and how to improve their remanufacturability.

Company size
The business of the company increased significantly once it had been acquired by Xerox in 2011. Due to this acquisition, the volume of remanufactured products in the company increased by 25-30 per cent because there are more cores available to remanufacture. The cores come from new products that are sold to customers by Xerox and then come back to Company D. Before the company was acquired by Xerox, it had a lower volume of cores supplies.

Cores sorting
Company D selects certain photocopier models to be remanufactured because some models are not suitable for remanufacturing. The models will only cause problems in the future if they are remanufactured. In addition to selecting certain models to be remanufactured, the company organise sorting to cores that arrive at the facility. The purpose of the sorting are as the following:

(1) Assess the potential cost to remanufacture

(2) Estimate the potential selling price of the remanufactured products

Electronic instrument to record customer use pattern
There is an instrument attached to the photocopiers that provides information about the historical use of the products. The instrument can be generally useful for disassembly and remanufacturing because of the reason as explained by the manager:

'…there is an electronic meter that will tell you how many A4 sheets, how many A3, how many scan, how many prints, how many prints you have sent to it, because it's a MFD, multifunctional device'.

'*We can go in electronically and interrogate the machine. So, we can go into engineer access code, and say tell me the life that the drum has done. Tell me the life the fusion section has done, and how many paper jams the machine has done, tell me when these paper jams have occurred in the machine. So, it gives us areas to address...'*

The device helps employees to decide whether the components should be replaced with new ones. The company will decide to use the component again if the remaining value is high. This decision is important in disassembly as recovered components require more treatments during the post-physical disassembly process (e.g. handling and moving) compared to rejected components.

Skills of employees
Despite the fact that the company requires specialised skills in the products, the flexibility of the employees is still needed to some extent. This is largely due to the actual return rate of used products that cannot be predicted accurately. Major business trends like seasonal patterns can be predicted from previous years, but there are external factors that are difficult to forecast. For example, if any clients of the company move to other locations, then it will reduce the number of products that are leased. Conversely, the company needs to release new contracts when it obtains new customers. This situation increases the uncertainties of the business.

Process choices

MTO production system
Company D combines MTO and MTS, with the former being more dominant than the latter. The purpose of this dominance is to minimise the inventory close to zero. To support this aim, the company builds a facility where all the activities could be undertaken under one roof, which results in more efficient operations.

The main constraint of MTO adoption is the availability of new components. Orders could be met by using MTO operations, but the availability of the new components makes it more difficult to fulfil these orders. To overcome this, the company has developed buffer stocks in anticipation of unpredicted customer orders. The company holds on average stock of 25 units from a wide range of models.

Volume of cores supplies
Company D can manage the supply of cores very well because it obtains cores easily from customers who sign leasing agreements. The closed-loop supply chain in this company makes forecasting easier, since the new products launched by the company return to be remanufactured. The company's forecast of the volume of cores supplies is based on the volume of new products sold to customers.

Photocopier remanufacturing has substantially low volumes compared with the manufacturing process. Although the volume of remanufacturing is not high, photocopier remanufacturing is feasible because the cost of operations, which mostly consists of labour cost, is relatively low compared to the potential reclaimed value.

Tools and equipment
The workers use mostly general tools and equipment during the physical disassembly activites. Most of the tools and equipment that are required to carry out disassembly can be obtained in the market place. Due to the sensitivity of some components, certain treatments are needed during handling and moving in the post-physical disassembly activities. For example, there are roughly 20 sensors in photocopiers, depending on the model. The sensors are small and fragile, so they cannot be mixed with other components when they are handled and moved, as they can be lost or broken. Another example is an OPC (Organic Photo Conductor) drum that cannot be touched. The consequences of this is that different components require different treatments and more equipment is needed for different components.

Skills of employees
The employees tend to have specific skills rather than general ones. The manager explains that a good candidate should have a mechanical aptitude, a good memory and be a logical thinker. An engineering degree or experience in another position that deals with mechanical products would also be a good start.

Product attributes

Value of recovered products
In general, the potential value of recovered products within photocopiers is high. The potential recovered value will exceed the cost of remanufacturing because the expected selling price exceeds the acquisition cost of the cores. In certain cases, when the photocopiers are not remanufactured, the company decides to undertake selective disassembly to recover high value components only.

From the perspective of customers, high product specifications offer higher benefit compared low specification. This is because the price difference between new products and remanufactured products is bigger for products with high specification. In addition, photocopiers with high specification are more often remanufactured, even though smaller types are also possible to be remanufactured.

The retail price of a new product model will decrease significantly after its introduction. For instance, the price of a new model can decrease by as much as 40%, just 6 months after its introduction, and the price will remain stable from then on.

Innovative versus functional products
Some of photocopier models are slightly innovative with technological advancement but most of them are functional whose value relatively stable over time. The constraint on how many times that photocopiers can be remanufactured is not the product's obsolescence, but instead the availability of its parts. The products could be remanufactured many times over, but remanufacture should stop when there is no longer a supply of parts from the manufacturers. This happens about 8 years after the product's launch, when the manufacturer is no longer producing the new parts that are needed for the models.

Technological advances that make fundamental changes to photocopiers is unlikely to happen in the future. Minor changes, such as the incorporation of a new design to increase functionality, and cosmetic changes to increase the product's aesthetics might happen. However, fundamental changes, such as the transformation from analogue to digital technology, are less likely to happen again. These conditions lead to greater opportunities for the remanufacturing business.

Sequence of disassembly

There is a work instruction that gives employees details of a specific disassembly sequence that should be followed, and explains which modules or components that should be taken before others. Employees should follow these procedures.

Level of disassembly

The company attempts to find the optimum level of disassembly to improve efficiency. All of the modules are taken out from the chassis and then the components from the modules. Nevertheless, not all the components are taken out from the modules. In other words, the machines are disassembled completely at module level, but the modules are not stripped off completely into the lowest components. The modules are disassembled to a level where cleaning and testing can be undertaken. Some modules cannot be separated into components because the disassembly process will break them.

Type of materials

The types of materials that are used for photocopiers are quite diverse that mainly consist of steel, plastics and other materials. The variety of materials requires different treatment during the physical disassembly activities and the post-physical disassembly activities. For example, materials that are made of plastics are lighter but they are easier to scratch than those made of steel, particularly when they are moved and handled. Similarly, a censor requires different treatments as it is made of plastic, sensitive and could be easily broken.

Number of components

Different product models have a different number of components, with the higher product specification models having more components. All photocopiers essentially work in the same way and consist of similar modules, regardless of the model. For example, the Xerox WorkCentre 7556 family, which is one of the most popular models amongst customers, has as many as 3,032 components. These components include a paper cassette, paper feed, registration roller, exposure lamp, OPC (Organic Photoconductor) drum, charge corona, toner unit, fuser unit and many others. These modules are found in any model, as they are the main constituents of photocopiers. Disassembled components require grouping when they are moved and handled, due to the high number of them. This occurs during the post-physical disassembly activity.

Ecodesign principles

There is an interesting finding regarding the adoption of ecodesign principles. Although Company D is part of an OEM, there is no clear information regarding its adoption of ecodesign. There has been an increasing trend towards the use of common components that can be used for a number of different product models. The respondent admitted that the photocopiers get easier to remanufacture compared to previous years, but he was not convinced this was the intention of the OEM.

Larger photocopiers are easier to remanufacture because the products use modular designs. These enable remanufacturers to disassemble, upgrade and install new software. The average weight of a photocopier is 100 kg – 50% of it is steel, 30% plastic and 20% is a mixture of different metals.

Product variety of photocopiers

The parent company has launched many new models of digital photocopiers to fulfil the different needs of its customers. It has been a big challenge for the company to remanufacture a wide variety of these models. To overcome the issue, the company has initiated a shift from remanufacturing the full products to remanufacturing sub-assemblies and components. This strategy allows the company to upgrade the remanufactured sub-assemblies and components into a new model.

APPENDIX IVE: Case Study Report of Company E

Business operations

Company E is part of a global jet engine manufacturer that is focusing on remanufacturing services, as part of its maintenance, repair and operations procedures. The company has 600 employees of which about 60 work on the disassembly operations. The company delivers services to over 120 customers, which consist of commercial, military and business customers. The types of engines that are remanufactured in the company include V2500, AE 2100, Tay, Adour and BR710.

Company E delivers a product-service package to customers, which are mostly airline companies. This is based on a leasing agreement, whereby airlines purchase the service from the company based on 'power by the hour'. The rate of 'power by the hour' – i.e. an agreed fee with the airline regarding the cost for an engine to fly for one hour – is determined by various factors that constitute 'product attribute data'. These attributes determine the risk of engine potential failure, such as the age of the engine, the type of the engine, the location of operations, etc.

The cost of remanufacturing for jet engines can be traced more accurately to each engine. This is different from other products whose costs are usually only estimations. Jet engine remanufacturing can cost between £23,000 and £30,000, contingent on various factors.

The manufacturing process of jet engines starts when the company receives information regarding cores condition from Engine Health Management System (EHMS). The information from EHMS, which is combined with data from log-book, is used to prepare resources needed for remanufacturing. At this point it is possible that the company decides to postpone cores arrival and keeps the engine flying. This case occurs when the company does not have required resources to carry out remanufacturing for the engines. The process of the remanufacturing is presented in Figure IVE.1.

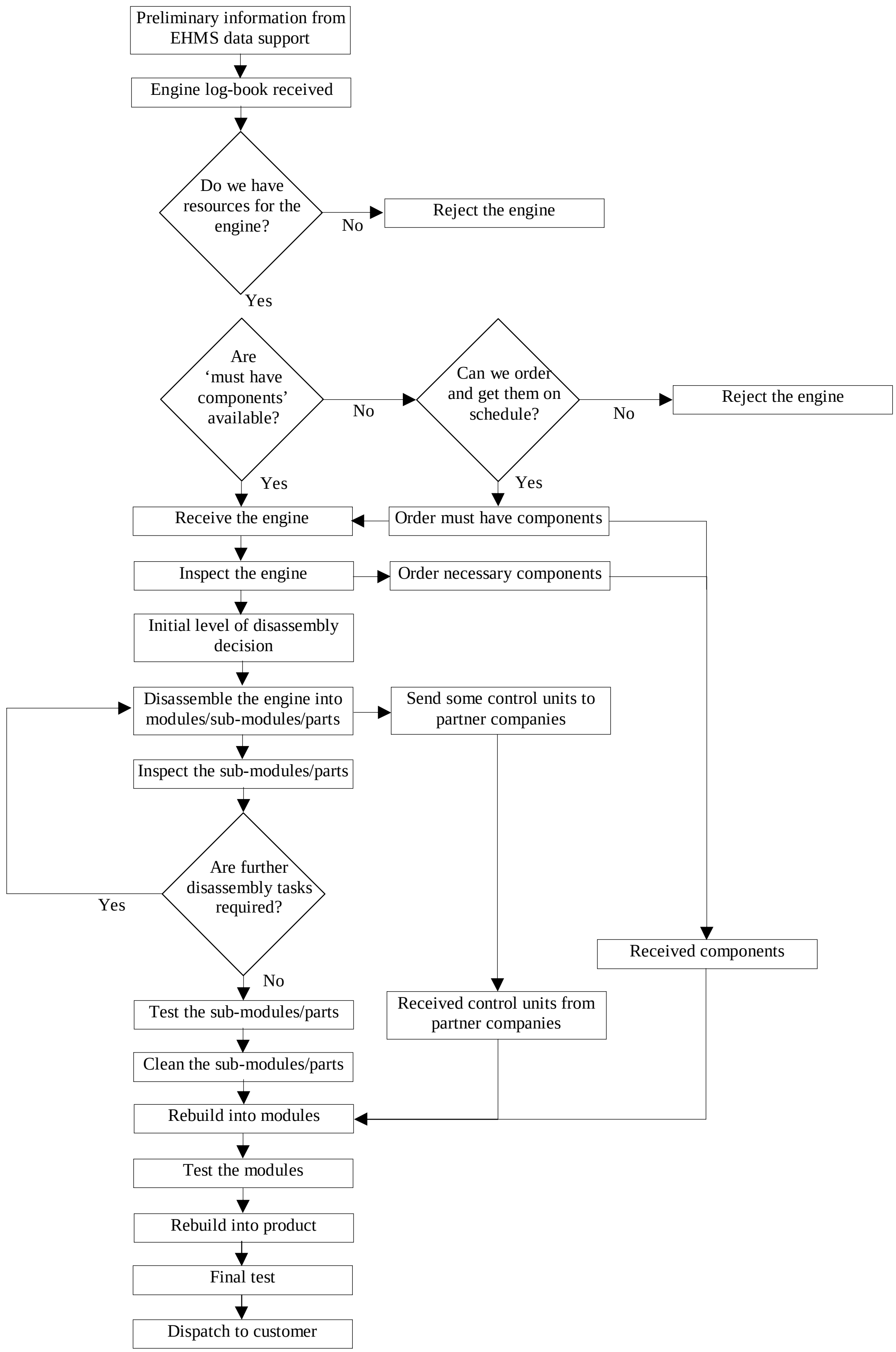


Figure IVE.1. Remanufacturing process in Company E

Sources of uncertainties

As has been previously mentioned, uncertainties regarding the quality of the cores' are managed with EHMS. There are several factors that cause the quality of cores is uncertain. Figure IVE.2 presents various factors that make quality of cores highly varied. The variations of cores quality leads to uncertainties in disassembly process. The sources of uncertainties and how they affect disassembly are discussed below.

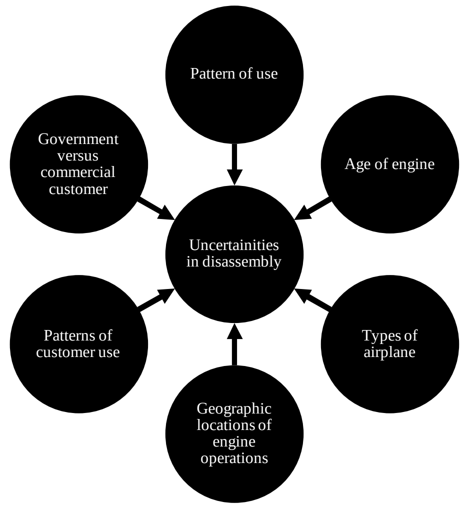


Figure IVE.2. Sources of uncertainties in jet engine disassembly

Flight cycle

Flight cycle refers to the use of an engine for one take-off and landing of an aircraft. There will be difference in the damage caused to the engines between those that are used in longer flights, but less frequently, and engines that are used for more frequent but shorter flights. Engines that operate for short distances have higher flight cycles and their life-limited parts need replacing more frequently. Thus, higher flight cycles require higher disassembly costs due to the need for more replacement parts.

Geographical location of engine operators

Airplanes operating in oceanic areas have different problems with those that fly over desert areas. A large amount of salt in the air in oceanic areas causes problems to certain components in the engines. On the other hand, it is the dust that causes problems to the engine components of airplanes that operate in desert areas. As a result, the components of jet engines that need to be disassembled are not the same. Other conditions that may cause problems include the temperature and humidity of the environment.

Age of the engine

The age of the engines affects the number of components that are damaged and the type of damage that is caused to the various parts. Old engines typically require more disassembly works due to higher number of part replacements. The products also need higher disassembly level compared to newer engines.

Types of airplane

Type of airplanes causes a big difference in remanufacturing costs. For example, a V2500 jet engine model is used in Airbus 318, 319 and 321. V2500 is installed in Airbus 318 and 319, which produces 22,000 thrust, while the same engine that powers Airbus 321 produces 33,000 thrust. The engine type installed in Airbus 321 produces almost twice the amount of thrust and, consequently, affects the remanufacturing costs because there is greater number of components need for replacements.

Behaviour of the users
This uncertainty is difficult to forecast, since it is related to the behaviour of individual users. For example, some pilots tend to reduce thrust in certain weather conditions but others are more likely to increase it. These differences cause variances in the number of damaged parts and the need for replacements.

Commercial versus government customers
Governments are less sensitive to cost because the budget has already been allocated. Therefore, incoming cores from governments are more stable because they are not governed by seasonal patterns. Meanwhile, cores from commercial customers have seasonal patterns. For example, the jet engines used for small plane are usually rented during the summer holidays and then remanufactured after the holiday period ends. Airplanes used by government bodies do not have this kind of pattern.

Engine health management system (EHMS)
The company relies on data that has been retrieved from EHMS for managing manage uncertainties during disassembly. The system is used to carry out on-engine monitoring system, which is primarily used to reduce maintenance costs and avoid service disruption. This system is added to the currently existing well-established safety system, which is controlled in Derby, England, and supported by 170 staff, as well as several other locations, including Bristol, England, and Dahlewitz, Germany.

The system produces indicators to identify potential damage, problems and any work that may be necessary before the engines arrive at the facility. To support EHMS, the engine is fitted with roughly 25 sensors that identify different indicators, which will then be transferred to the pilot and ground staff. The critical engine characteristics that have been included in the parameters are the temperatures, pressures, speed, flows and vibration levels. It is the task of the EHMS to monitor whether those parameters are still within the tolerance level and, if they are not, EHMS should give some advice and explanations about these issues.

Disassembly process

Physical disassembly activities are undertaken manually by human without any machinery assistance. This is mainly because there are a large number of components, so it is difficult to develop an automated disassembly. The manual method offers flexibility during remanufacturing of jet engines, but it can also create a challenge. Manual configuration hinders the company's ability to react in a timely manner when a quick changeover is needed. This situation could increase the lead-time that is needed to deliver the product to customers.

The process of remanufacturing jet engines is identical with that used to remanufacture other products, which mainly consists of stripping cores, identifying problem, rebuilding, testing, delivering and sending invoice. Jet engine remanufacturing is divided into several gates and the disassembly process is located in gate 2, as depicted in Figure IV.3 on the next page.

Procedures of disassembly process
Company E's disassembly process is guided with formal procedures. The company carries out compliance work every day before the employees start to work. This is to ensure that the tools used to do the jobs are fit for purposes and to confirm that the person doing the job possesses the right skills and competencies.

There are many complicating factors that can make disassembly difficult, including limited access when stripping it down, and either thermo detersive or corrosion of the components. In addition, the disassembly process requires tools and equipment that are specific. Some tools and equipment for manufacturing of jet engines might be useful but they are not always suitable. This is because disassembly is not always the reverse of assembly.

Pre-physical disassembly activity
The company needs to obtain information before the engine arrives at the facility, as presented in Figure IVE.3. During pre-induction, at Gate 0, the company should have gathered a certain amount of

information. It must also have met and agreed on what jobs and tasks it needs to do. This is intended to reduce the amount of variations that come in.

EMHS provides information that enables the company to organise its pre-physical disassembly activity. This includes the preparation of tools and equipment, an estimation of work scope and the preparation of a work break down structure (WBS). The WBS allows the company to show that it has complied with the requirements that are set up by regulatory bodies as well as record accurately what has been done. These activities are carried out four to ten days before the engines arrive at the company.

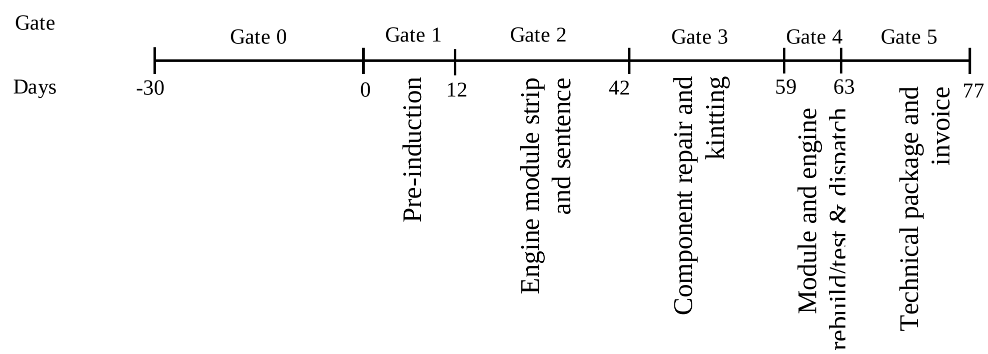


Figure IVE.3. Time guidance of engine streamer process

Physical disassembly activity
Although some of the decisions have been made in pre-induction, the final decision regarding the level of disassembly is quite a complex process. Once the modules have been disassembled into sub-modules, each of them is assessed to find out to what extent it needs to be further disassembled. The level of the work scope determines the level of disassembly and this can be any level from 1-3, with fractions between them. The level of disassembly varies from 1.0 to 3.0, with the value of 1.0 indicate the lowest level of disassembly, while 3 is the highest.

All key components always come with a document that provides a clear direction about what is needed to be done with each of the parts, and who does what. The components should then be reassembled into the same engine. Each key component has a unique serial number, which requires that the components be reassembled into the same engines.

Post-physical disassembly activity
The majority of costs during disassembly are caused by damages during physical disassembly activities. Moving and handling disassembled components are also risky as they need careful treatments. These risks have the potential to be very costly for the company. Reducing the probability of damage during disassembly is important because scrapping the components is very expensive. To avoid the damages, employees should use customised design tools and equipment.

During the post-physical disassembly activities, there is a part classification process to classify components according to their importance. General components, such as wire, nuts or harnesses, do not have a unique serial number, but other main components, like turbine disks do. The components with unique serial number should be reassembled into the same engine.

As presented in IVE.1, the disassembly process in jet engines iterates with the other processes in remanufacturing. It is not a mutually exclusive activity, but overlaps with other activities, such as testing, cleaning, washing and the procurement of new parts. The decision to conduct further physical disassembly activities or not depends on the results of the subsequent process after disassembly – i.e. inspection, cleaning and testing. The higher the level of disassembly indicates the need for more work to be undertaken and, consequently, more costly operations.

Organisational characteristics

Company E operates in a highly regulated industry. The industry standards, which are organised by The International Aviation Safety Association (IASA) and Civil Aviation Authority (CAA), cover various aspects, not only about the technical specification of the engine, but also human resource, business architecture, infrastructure architecture, information architecture and software architecture amongst others. These regulations create constraints for the company when it organises its operation.

The company offers a product-service system as its business model, which is also commonly referred to as leasing. This business model develops a closed-loop supply chain that hinders independent remanufacturers from entering the jet engine remanufacturing business. For example, approximately 90% of Trent 700 jet engines are operated by airline companies under power-by-the hour contract. Accordingly, there is a small opportunity for other parties to capture the rest 10% of the market. The need for high cost investment is also the reason why independent remanufacturers are not able to enter the jet engine remanufacturing business.

There are several advantages to offering leasing agreements to customers as part of remanufacturing program, including:

- Most engines that are leased out to customers come back to the company, so that the circulation jet engines form a closed-loop supply chain and the arrival of engines becomes more predictable.
- It is very likely that employees who remanufacture the engines do not need to acquire new skills as they have remanufactured engines in the past.
- The company can manage the product history, which is useful to identify potential problems during the remanufacturing process.

Knowledge sharing
Company E receives support from its parent company who manufactures jet engines. Product specification, engine manuals and the standards for testing are amongst the knowledge that is transferred from the manufacturing division to the company. The knowledge provided by the OEM is sometimes not applicable to remanufacturing. Disassembly knowledge, which is not available in the manufacturing division, has to be developed by the company itself.

Cores sorting
EHMS can function like cores sorting in some ways. It assesses the condition of the engines so that the company can decide on whether to accept or reject the engines before their arrival. Cores sorting, which typically requires a small team to undertake the task, is replaced by EHMS, which is operated by a group of staffs located in Derby.

Based on information from EHMS, Company E can either accept or reject the engines. Information from EHMS can identify which parts that can be remanufactured and which ones that should be replaced with the new ones. If the new parts for replacement are either not available or difficult to obtain, the company can refuse the engines. Another alternative is to try to make the engines fly longer while waiting until the parts become available.

Product information data base
Jet engines can be remanufactured 8-9 times during their life cycle. To support the remanufacturing process, Company E uses product history stored in product information database that record product history. The information in the system predominantly comes from two sources: EHMS and the engine logbook. If data from the logbook is not accurate, the company send staff to check the engines physically. This is the reason why the company needs a period up to 10 days before they can induct the engines.

Made-to-order production system
The company operates the made-to-order system that is supported by reliable forecasting, which is used to avoid a large amount of financial resources being stuck on large stocks of parts. There are some parts that should be readily available in warehouse, particularly those that are life limited. Nevertheless, other parts

are only ordered when remanufacturing orders have been received. Experienced staffs are employed to carry out the forecast, which is supported with historical data. For example, approximately 25% of the blades in an engine are scrapped during the first remanufacturing process.

Volume of cores supply

The volume of cores affects the remanufacturing operation for two reasons. First, a certain volume of cores is needed to maintain the skills of the employees and keep them qualified. Second, a certain number of cores enables the company to exchange engines that belong to the same party provided that owner agree to this plan. The plan is applied when the ordered parts from the suppliers have a long lead-time.

Tools, equipment and employee skills

The company utilises customised tools and equipment that are operated by employees with specific skills to carry out certain jobs. The tools and equipment for the jobs have been specified in the engine manual and these must be followed. The engine manual explains what tools needed to carry out certain tasks.

Employee skills are organised through a people skills matrix that is updated in real time and reviewed quarterly. The competency matrix, which explains which employees can do which tasks, is accompanied by an assessment program to ensure that the company maintains these skills. If something new comes along, the company will send its staff for training so that they can learn to use the new tools. The skills are mandated by regulatory authorities, such as the CAA and IASA that monitor how companies in the industry train people and maintain their capabilities.

Employee skills and qualifications

Employees who carry out disassembly require formal qualifications obtained from education and trainings. In addition to these, they must also possess experiences and pass examination. It is possible that some employees lose their competence after certain periods of time. For example, the company used to remanufacture Pegasus and Harrier Jump Jet in the past but they do not operate airplanes anymore, so employees lost their competencies.

Product attributes

Company E has adopted good practice that is very strict, considering the high value of the components. In some areas, the employees are not allowed to wear a ring, belt buckle or any other accessories containing metal, as they could all potentially damage components. The employees should also wear gloves when touching, moving or handling blades to avoid fingerprints on them. This usually happens in the post-physical disassembly process, where there are considerably higher numbers of engine components.

Life cycle of jet engines

Jet engines have a high value that is relatively stable and can last up to 20-35 years. Considering how long they last, the engines can be categorised as functionally oriented rather than innovative products. Innovation in jet engines is very rare. For example, the company estimates it takes at least 10 years to develop an open-rotor that will save 30% save of fuel.

Source of value

The value of cores comes from two main sources: the materials and the production process of the cores. The material used to produce the cores is mainly titanium, which is very expensive and getting more difficult to obtain. The recovered value from this source is relatively stable and could even rise as the availability of this material is rare.

The other source of value is created from the production process. This value is less stable in comparison in comparison to the previous one. It decreases over time due to products wearing out and the introduction of new technology. The high value of jet engines produced by the advanced manufacturing process makes the remanufacturing industry interesting economically. This is because the cost to remanufacture jet engines is much lower than the cost to make the new one.

Ecodesign principles

The manufacturing company adopts modular designs to make the assembly of jet engines easier. These modular designs are not only useful for manufacturing, but also for disassembly process in the remanufacturing. Jet engines, which typically consist of eight modules, are broken down into different modules and each of them is disassembled at a different level; they do not have to be completely disassembled. The manufacturer of jet engines seemed to focus less on ecodesign principles and more on reliability, persistence, specification and accuracy, since all of these deal with safety issues.

APPENDIX V – Response from member of expert panel

APPENDIX V – Response from member of expert panel

QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
Part II		Description of the framework regarding disassembly strategy
Part III	:	Validating the relevance of the framework to practice
Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) : [redacted], PhD.
2. Job title/role : COMMUNICATIONS, ENVIRONMENTAL CONSERVATION
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : 4
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : 8
5. What type of products are remanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : Automotive, off-road equipment (electronics recycling)

Please read the framework of disassembly strategy in PART II, and then answer the questions in PART III and IV.

PART II. DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
Stability of cores supply	:	This factor consists of dimensions including: relationship with cores suppliers, type of relationship with OEMs, company size of the remanufacturer, and volume of cores supply.

Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.

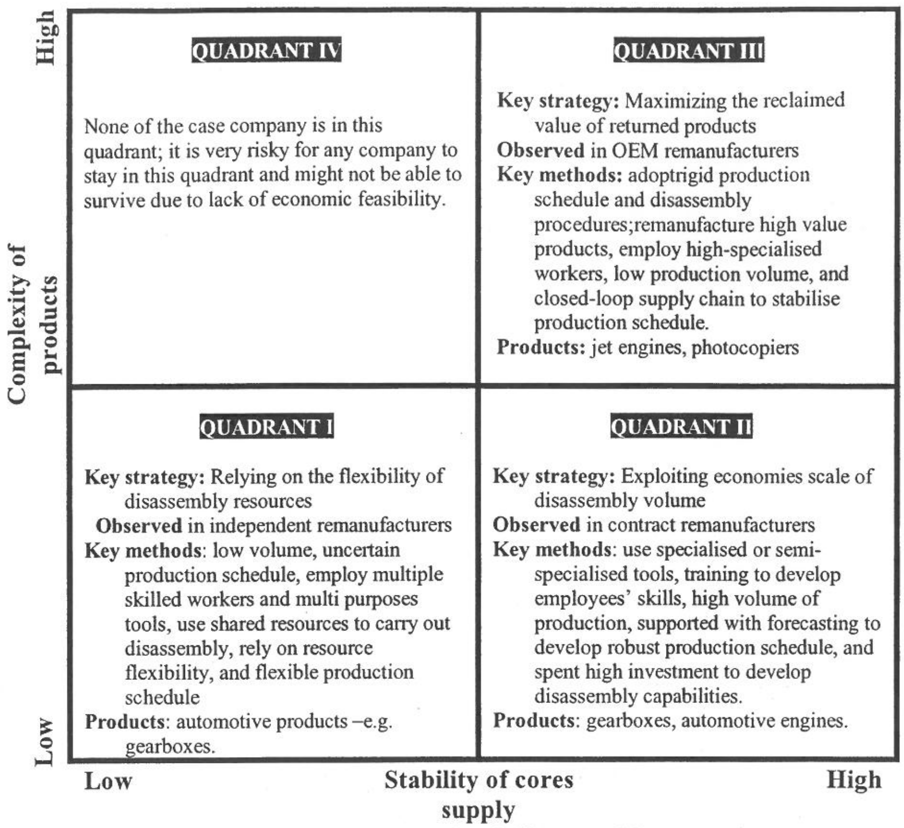


Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
OEM remanufacturers	:	companies that remanufacture on behalf of the OEMs and typically, but not always, receive support from the OEMs.
Independent remanufacturers	:	companies that remanufacturers other parties' products without licences, support or long term commitment from OEMs.

This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered.Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar toa mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned components
Typical adopters of the strategiesof this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companiesis located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of the framework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					X	
2.	Disassembly strategies presented in the framework above are important for remanufacturing companies.						X
3.	The disassembly strategy framework can be implemented in real practice.				X		
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.					X	
5.	The framework is not useful for remanufacturing companies in organising present operations.		X				
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.						X
7.	Not understanding the disassembly strategy framework above may cause remanufacturing companies adopt the wrong strategies.				X		
8.	I find the framework above is difficult to follow.		X				
9.	There are many major issues missing from the framework.		X				
10.	The disassembly strategy framework described above is an important area to address.						X
11.	The framework above does not represent disassembly strategies to any great extent.		X				
12.	The disassembly strategies presented in the framework are useful in some way.						X
13.	The framework can be used to help remanufacturers improve disassembly.				X		
14.	The framework above looks like it has potential to help managers make better decisions.					X	
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.					X	

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

Not to the framework itself, but accompanying information would be useful for companies new to remanufacture e.g examples of high & low stability, examples of companies /products that fall under each quadrant. Also, explanations on WHY each strategy works best.

2. *Could you please provide any suggestions for how to make the above framework more relevant to practice?*

Think about how/where the framework could be used (i.e context) e.g websites with general information for remanufacturers, presentations, textbooks etc.

Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:...

[redacted]@hotmail.co.uk

QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
Part II		Description of the framework regarding disassembly strategy
Part III	:	Validating the relevance of the framework to practice
Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1.	Name (optional)	:	[redacted]
2.	Job title/role	:	PRODUCTION MANAGER.
3.	How long have you worked in the remanufacturing field? – Either as a researcher or practitioner.	:	8 YRS
4.	How many remanufacturing companies have you worked with and/or have you visited to carry out research?	:	3 (within [redacted]).
5.	What type of products areremanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research).	:	N/A.

Please read the frameworkof disassembly strategy inPART II, and then answer the questions inPART III and IV.

PART II.DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
Stability of cores supply	:	This factor consists of dimensions including: relationship with cores suppliers, type of relationship with OEMs, company size of the remanufacturer, and volume of cores supply.

Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.

Complexity of products \ Stability of cores supply	Low	High
High	**QUADRANT IV** None of the case company is in this quadrant; it is very risky for any company to stay in this quadrant and might not be able to survive due to lack of economic feasibility.	**QUADRANT III** **Key strategy:** Maximizing the reclaimed value of returned products **Observed** in OEM remanufacturers **Key methods:** adoptrigid production schedule and disassembly procedures;remanufacture high value products, employ high-specialised workers, low production volume, and closed-loop supply chain to stabilise production schedule. **Products:** jet engines, photocopiers
Low	**QUADRANT I** **Key strategy:** Relying on the flexibility of disassembly resources **Observed** in independent remanufacturers **Key methods**: low volume, uncertain production schedule, employ multiple skilled workers and multi purposes tools, use shared resources to carry out disassembly, rely on resource flexibility, and flexible production schedule **Products**: automotive products –e.g. gearboxes.	**QUADRANT II** **Key strategy:** Exploiting economies scale of disassembly volume **Observed** in contract remanufacturers **Key methods**: use specialised or semi-specialised tools, training to develop employees' skills, high volume of production, supported with forecasting to develop robust production schedule, and spent high investment to develop disassembly capabilities. **Products**: gearboxes, automotive engines.

Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
OEM remanufacturers	:	companies that remanufacture on behalf of the OEMs and typically, but not always, receive support from the OEMs.
Independent remanufacturers	:	companies that remanufacturers other parties' products without licences, support or long term commitment from OEMs.

This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered.Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar toa mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned components
Typical adopters of the strategiesof this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companiesis located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of theframework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					✓	
2.	Disassembly strategies presented in the framework aboveare important for remanufacturing companies.						✓
3.	The disassembly strategy framework can be implemented in real practice.					✓	
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.				✓		
5.	The framework is not useful for remanufacturing companies in organising present operations.		✓				
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.				✓		
7.	Not understanding the disassembly strategy framework above may causeremanufacturing companies adopt the wrong strategies.				✓		
8.	I find the frameworkabove is difficult to follow.			✓			
9.	There are many major issues missing from the framework.		✓				
10.	The disassembly strategy framework described above is an important area to address.				✓		
11.	The framework above does not represent disassembly strategies to any great extent.				✓		
12.	The disassembly strategies presented in the framework are useful in some way.					✓	
13.	The framework can be used to help remanufacturers improve disassembly.					✓	
14.	The framework above looks like it has potential to help managers make better decisions.					✓	
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.					✓	

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

Companies that remanufacture various products with equal qty's may be able to sit in various quadrants.

2. *Could you please provide anysuggestions for how to make the aboveframework more relevant to practice?*

—

Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:...

QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
Part II		Description of the framework regarding disassembly strategy
Part III	:	Validating the relevance of the framework to practice
Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) : [redacted]
2. Job title/role Teamleader. : Technician/Teamleader
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : 35 Years.
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : 4
5. What type of products areremanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : Engines / gearbox. Airbrake Products. Truck & Bus Units.

Please read the frameworkof disassembly strategy inPART II, and then answer the questions inPART III and IV.

PART II.DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
Stability of cores supply	:	This factor consists of dimensions including: relationship with cores suppliers, type of relationship with OEMs, company size of the remanufacturer, and volume of cores supply.

Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.

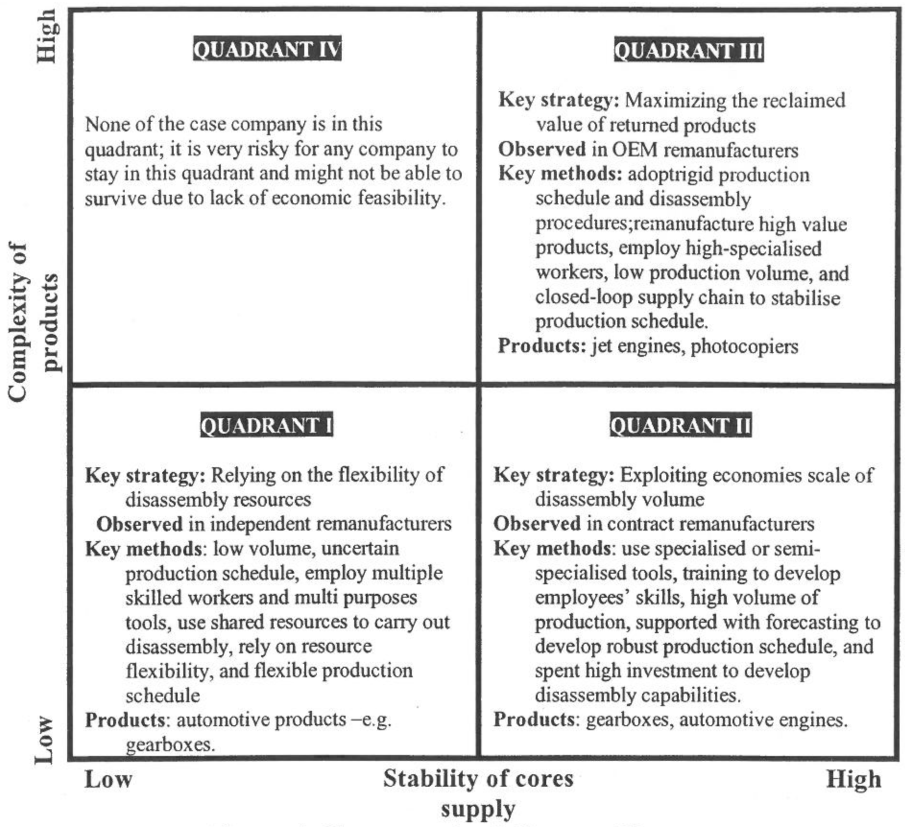


Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
OEM remanufacturers	:	companies that remanufacture on behalf of the OEMs and typically, but not always, receive support from the OEMs.
Independent remanufacturers	:	companies that remanufacturers other parties' products without licences, support or long term commitment from OEMs.

This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered.Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar toa mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned components
Typical adopters of the strategiesof this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companiesis located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of theframework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					✓	
2.	Disassembly strategies presented in the framework aboveare important for remanufacturing companies.					✓	
3.	The disassembly strategy framework can be implemented in real practice.					✓	
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.					✓	
5.	The framework is not useful for remanufacturing companies in organising present operations.				✓		
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.				✓		
7.	Not understanding the disassembly strategy framework above may causeremanufacturing companies adopt the wrong strategies.					✓	
8.	I find the frameworkabove is difficult to follow.		✓				
9.	There are many major issues missing from the framework.			✓			
10.	The disassembly strategy framework described above is an important area to address.			✓			
11.	The framework above does not represent disassembly strategies to any great extent.			✓			
12.	The disassembly strategies presented in the framework are useful in some way.					✓	
13.	The framework can be used to help remanufacturers improve disassembly.					✓	
14.	The framework above looks like it has potential to help managers make better decisions.					✓	
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.					✓	

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

2. *Could you please provide anysuggestions for how to make the aboveframework more relevant to practice?*

Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:...

QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
Part II		Description of the framework regarding disassembly strategy
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Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) [redacted] :
2. Job title/role Team leader. :
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : 33
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : worked with 2.
5. What type of products areremanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : Bus - Rail - marine milling off-highway.

Please read the frameworkof disassembly strategy inPART II, and then answer the questions inPART III and IV.

PART II.DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
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Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.

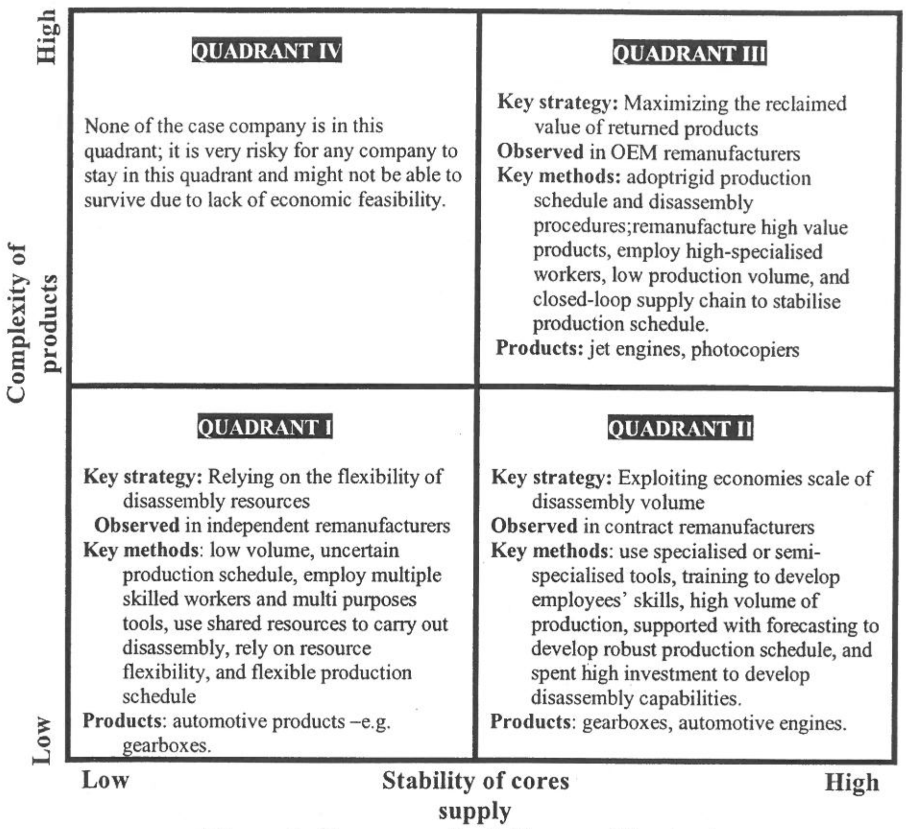

Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
OEM remanufacturers	:	companies that remanufacture on behalf of the OEMs and typically, but not always, receive support from the OEMs.
Independent remanufacturers	:	companies that remanufacturers other parties' products without licences, support or long term commitment from OEMs.

This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered.Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar toa mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned components
Typical adopters of the strategiesof this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companiesis located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of theframework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					✓	
2.	Disassembly strategies presented in the framework aboveare important for remanufacturing companies.					✓	
3.	The disassembly strategy framework can be implemented in real practice.					✓	
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.					✓	
5.	The framework is not useful for remanufacturing companies in organising present operations.			✓		[illegible]	
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.				✓		
7.	Not understanding the disassembly strategy framework above may causeremanufacturing companies adopt the wrong strategies.					✓	
8.	I find the frameworkabove is difficult to follow.			✓			
9.	There are many major issues missing from the framework.				✓		
10.	The disassembly strategy framework described above is an important area to address.			✓			
11.	The framework above does not represent disassembly strategies to any great extent.			✓			
12.	The disassembly strategies presented in the framework are useful in some way.				✓		
13.	The framework can be used to help remanufacturers improve disassembly.				✓		
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15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.				✓		

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I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

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PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) :
2. Job title/role BUSINESS MANAGER :
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : 27 yrs.
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : 10
5. What type of products areremanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : AUTOMOTIVE, MARINE, RAIL, WIND

Please read the frameworkof disassembly strategy inPART II, and then answer the questions inPART III and IV.

PART II.DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

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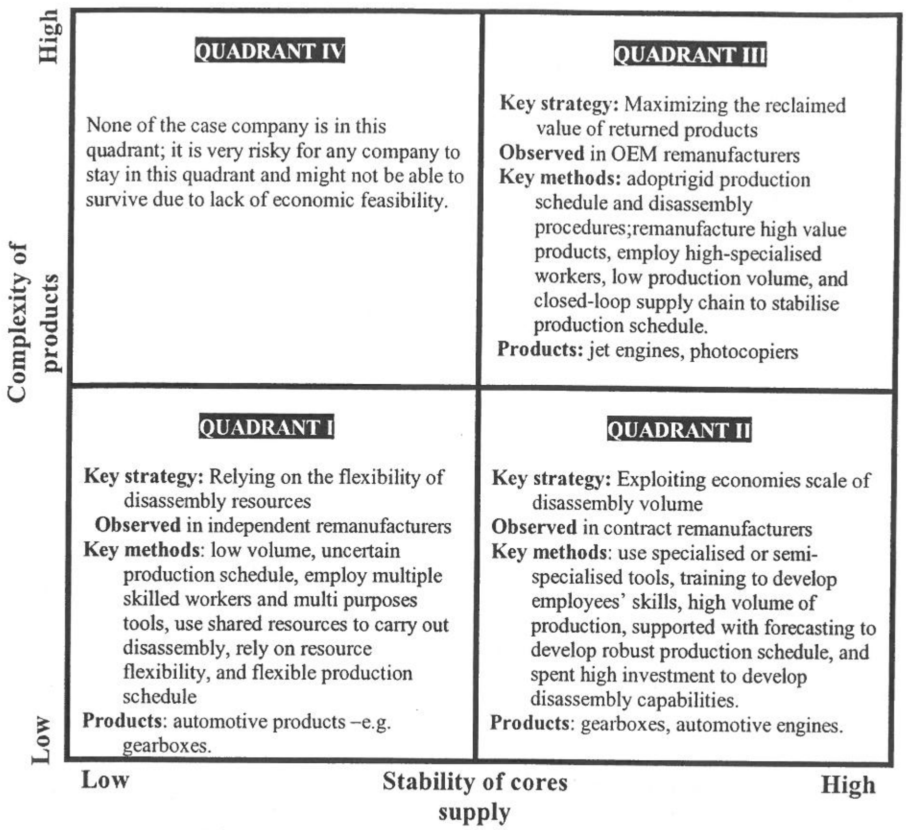

Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

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This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered.Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar toa mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

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Typical adopters of the strategiesof this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companiesis located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of theframework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					✓	
2.	Disassembly strategies presented in the framework aboveare important for remanufacturing companies.				✓		
3.	The disassembly strategy framework can be implemented in real practice.				✓		
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.				✓		
5.	The framework is not useful for remanufacturing companies in organising present operations.			✓			
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.					✓	
7.	Not understanding the disassembly strategy framework above may causeremanufacturing companies adopt the wrong strategies.				✓		
8.	I find the frameworkabove is difficult to follow.		✓				
9.	There are many major issues missing from the framework.				✓		
10.	The disassembly strategy framework described above is an important area to address.			✓			
11.	The framework above does not represent disassembly strategies to any great extent.				✓		
12.	The disassembly strategies presented in the framework are useful in some way.					✓	
13.	The framework can be used to help remanufacturers improve disassembly.			✓			
14.	The framework above looks like it has potential to help managers make better decisions.				✓		
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.				✓		

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

2. *Could you please provide anysuggestions for how to make the aboveframework more relevant to practice?*

Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:..

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QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
Part II		Description of the framework regarding disassembly strategy
Part III	:	Validating the relevance of the framework to practice
Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) : [redacted]
2. Job title/role : PhD Researcher, Glasgow Caledonian University
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : 2.75 yrs (Lecturer)
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : 4
5. What type of products areremanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : Gear Boxes (Auto/Manual) Engines. Photo copier.

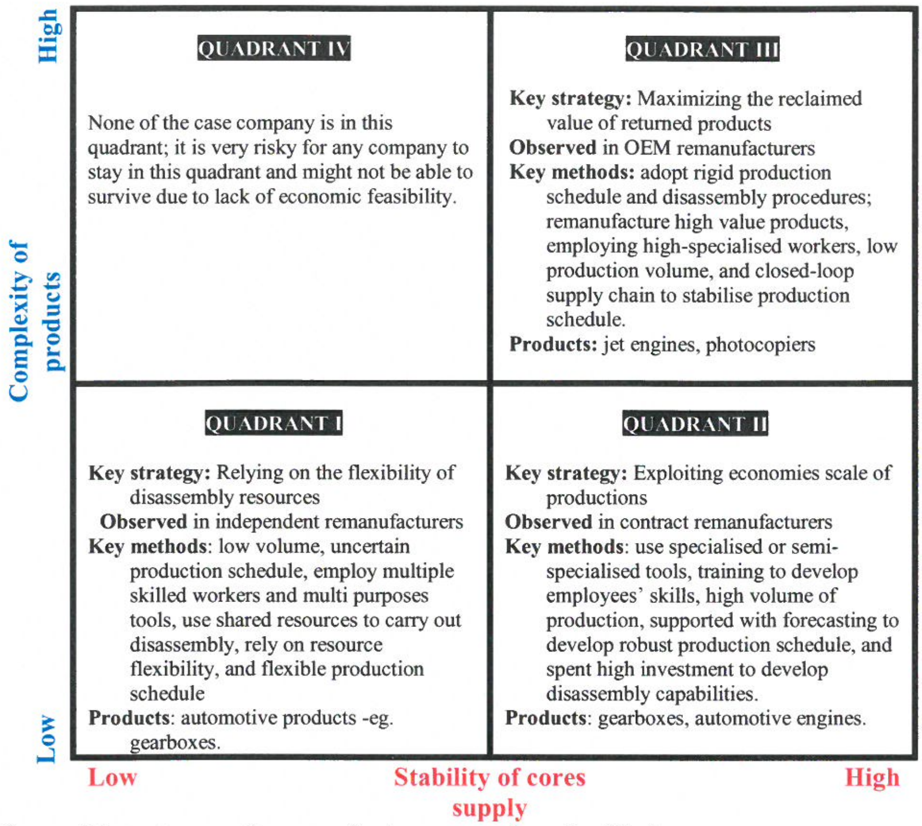
Please read the frameworkof disassembly strategy inPART II, and then answer the questions inPART III and IV.

PART II.DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
Stability of cores supply	:	This factor consists of dimensions including: relationship with cores suppliers, type of relationship with OEMs, company size of the remanufacturer, and volume of cores supply.

Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.



Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
OEM remanufacturers	:	companies that remanufacture on behalf of the OEMs and typically, but not always, receive support from the OEMs.
Independent remanufacturers	:	companies that remanufacturers other parties' products without licences, support or long term commitment from OEMs.

This description outlines the major differences between the disassembly strategies employed by remanufacturers in different quadrants, presented in Figure 1 above.

Key strategy of Quadrant I: Relying on the flexibility of disassembly resources
Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered. Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of productions
This quadrant is slightly similar to a mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned products
Typical adopters of the strategies of this quadrant are OEM remanufacturers, who attempt to recover high value of complex products. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companies is located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of the framework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.					✓	
2.	Disassembly strategies, as presented in the framework above, are important for remanufacturing companies to establish.				✓		
3.	The disassembly strategy framework can be implemented in real practice.				✓		
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.						✓
5.	The framework is not useful for remanufacturing companies in organising present operations.		✓				
6.	This model is an acceptable description of high-level strategies of disassembly for remanufacturing.				✓		
7.	Not understanding the disassembly strategy framework presented above will mean that remanufacturing companies adopt the wrong strategies.			✓			
8.	I find the model difficult to follow.				✓		
9.	There are many major issues missing from the framework.		✓				
10.	The disassembly strategy framework described above is an important area to address.						✓
11.	The model does not represent disassembly strategies to any great extent.		✓				
12.	The disassembly strategies presented in the framework are useful in some way.						✓
13.	The framework can be used to help remanufacturers improve disassembly.				✓		
14.	The model looks like it has potential to help managers make better decisions.					✓	
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.					✓	

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

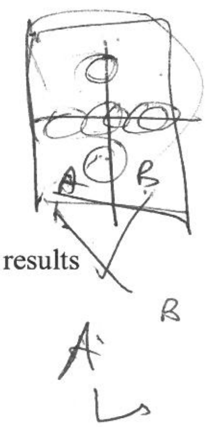
I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

Be more specific to disassembly as some points seems generally applicable to all steps in remanufacturing.

2. *Could you please provide any suggestions for how to make the above framework more relevant to practice?*

Discuss in greatest details, for each category of remanufacturers, which quadrant they fit in. As some remanufacturers may fit to more than one quadrant.



Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:...

[redacted] @gen.ac.uk.

QUESTIONNAIRE

This questionnaire consists of four parts with the following contents:

Part I	:	Background of respondent
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Part III	:	Validating the relevance of the framework to practice
Part IV	:	Recommendation to improve the relevance of the framework

PART I. BACKGROUND OF RESPONDENT

Could you please describe your expertise and experience in remanufacturing?

1. Name (optional) : [redacted]
2. Job title/role : - PhD reseacher - Curtin University Australia and Recturer
3. How long have you worked in the remanufacturing field? – Either as a researcher or practitioner. : - 4 years
4. How many remanufacturing companies have you worked with and/or have you visited to carry out research? : - 7 componies
5. What type of products are remanufactured in the companies you work with/carry out research? (Please mention all the products remanufactured in the companies that you work with/carry out research). : - Alternator, stater compresor, computer cartridge

Please read the framework of disassembly strategy in PART II, and then answer the questions in PART III and IV.

PART II. DESCRIPTION OF THE DISASSEMBLY STRATEGY FRAMEWORK

Remanufacturing companies adopt different strategies to carry out disassembly. Two main factors affecting disassembly strategy are complexity of cores and stability of cores supply. The dimensions that compose these factors are as follows:

Complexity of products	:	This factor consists of dimensions including: number of components, product structure, number of joints, and variety of materials used to make the products.
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Based on these factors, the strategies employed by remanufacturers can be categorised into four quadrants, as presented in Figure 1.

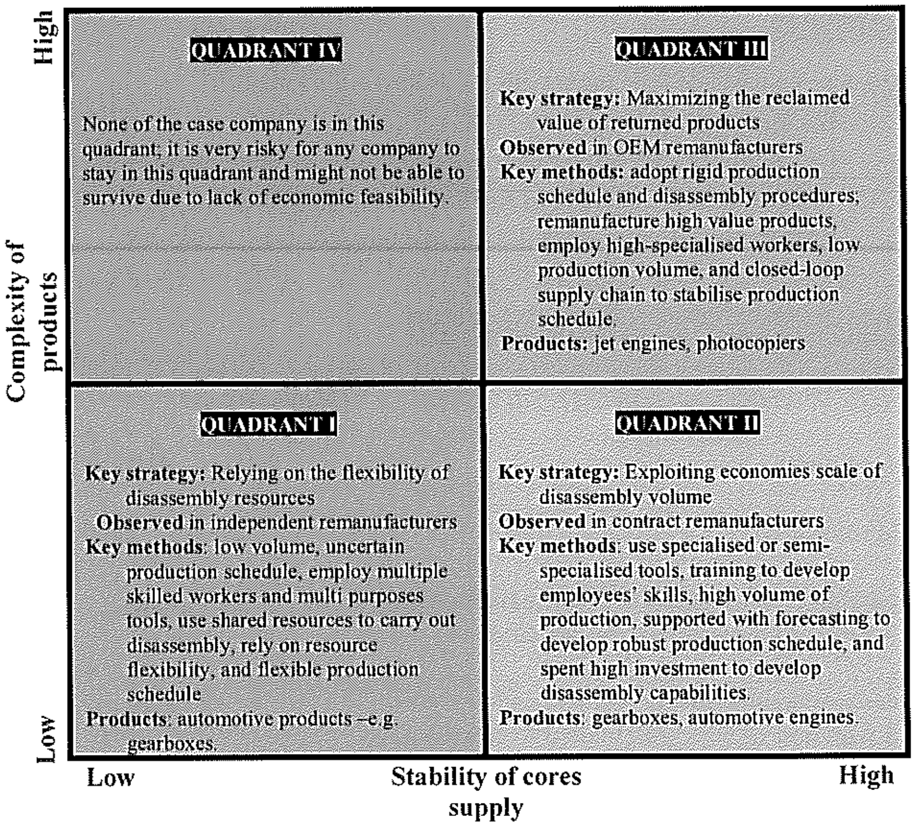

Figure 1. Framework of disassembly strategy

Definitions of three types of remanufacturers are described below:

Contract remanufacturers	:	companies that manufacture the products, who also carry out remanufacture alongside remanufacturing operations
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Remanufacturers in this quadrant rely on the flexibility of resources – i.e. employees, tools, equipment, and production schedules. Companies in this quadrant can charge premium prices to customers due to the customised services offered. Typical adopters of remanufacturers in this quadrant are small independent remanufacturers who serve niche markets and receive small order volumes from retail customers.

Key strategy of Quadrant II: Exploiting economies scale of disassembly volumes
This quadrant is slightly similar to a mass production system. The cores are disassembled in high volumes, using somewhat specialised tools and equipment. Remanufacturers organise cores sorting to increase the homogeneity of cores before they arrive at the disassembly facility.

Key strategy of Quadrant III: Maximising the reclaimed value of returned components
Typical adopters of the strategies of this quadrant are OEM remanufacturers, who attempt to recover high value of components. To achieve this purpose, the companies employ utilise highly specialised workers, and using rigid disassembly procedures. Companies are supported with a closed-loop supply chain so that the cores arrival is more predictable.

Key strategy of Quadrant IV: Not feasible quadrant
None of the case companies is located in this quadrant because it is very risky for any company to operate within this quadrant, and they might not be able to survive due to the lack of economic feasibility. Remanufacturing products with high complexity but lack of stability of cores supply is risky.

PART III: VALIDATING THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your personal opinion regarding the relevance of the framework presented in Figure 1 to the practice of disassembly for remanufacturing.

Could you please enter your answers by crossing the box that corresponds to the answer you have chosen?

No.	Statement	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1.	The framework closely represents real practice in remanufacturing companies.						X
2.	Disassembly strategies presented in the framework above are important for remanufacturing companies.						X
3.	The disassembly strategy framework can be implemented in real practice.					X	
4.	The framework helps me to understand the various strategies for carrying out disassembly processes.						X
5.	The framework is not useful for remanufacturing companies in organising present operations.	X					
6.	This framework is an acceptable description of high-level strategies of disassembly for remanufacturing.						X
7.	Not understanding the disassembly strategy framework above may cause remanufacturing companies adopt the wrong strategies.						X
8.	I find the framework above is difficult to follow.	X					
9.	There are many major issues missing from the framework.	X					
10.	The disassembly strategy framework described above is an important area to address.						X
11.	The framework above does not represent disassembly strategies to any great extent.	X					
12.	The disassembly strategies presented in the framework are useful in some way.					X	
13.	The framework can be used to help remanufacturers improve disassembly.						X
14.	The framework above looks like it has potential to help managers make better decisions.					X	
15.	The disassembly strategy proposed in the framework is useful for remanufacturing companies at the present time.						X

PART IV: RECOMMENDATIONS TO IMPROVE THE RELEVANCE OF THE FRAMEWORK

I would like to ask for your general opinion regarding how to improve the framework presented on page 1. Any comment would be highly appreciated.

1. *Could you please write in the space below any comments regarding possible improvement to the framework?*

* The framework presents systematic approach, however the reseacher may need to alter it so it can be translated across to industry For example
  - more industry specific language
  - expand the frame work to be more targeted to industry practice

2. *Could you please provide any suggestions for how to make the above framework more relevant to practice?*

* The researcher may need to ensure that the frame work coulde be published in book, journal, industrial conferenco which can be a guide for industry in implementing the strategies.

Thank you for taking the time to participate in this research. If you would like to receive the results of this research, please note your e-mail here:..

APPENDIX VI – List of publications

Priyono, A., U.S. Bititci, and W.L. Ijomah (2011). Balancing supply and demand in reverse supply chain: A case study in remanufacturing company, *Design for Innovative Value Towards a Sustainable Society*, pp. 552-557, Springer, Netherlands.

Priyono, A., U.S. Bititci, and W.L. Ijomah (2011). A literature review on reverse supply chain strategies: Identification of agenda for investigation, *The 1st International Conference on Remanufacturing*, University of Strathclyde, Glasgow, UK, 27-29 July 2011.

Priyono, A., U.S. Bititci, and W.L. Ijomah (2013). Human resource strategy for disassembly in remanufacturing, *The 20th EurOMA International Conference – Operations Management at the heart of recovery*, Dublin, Ireland, 7 – 12 June 2013.

Priyono, A., W.L. Ijomah and U.S. Bititci (2014). Disassembly for remanufacturing – A systematic literature review, new model development and future research needs, submitted to *Journal of Cleaner Production*, under-revision.