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Integrating Design for Remanufacture into the Design Process — the Operational Factors

by

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Abstract

Remanufacturing is the process of returning a used product to a like-new condition with a warranty to match. It is widely recognised as an environmentally preferable end-of-life strategy for many products, as it is a process that saves materials from landfill and retains more intrinsic energy than similar end-of-life strategies such as recycling or repair. The concept of ‘design for remanufacture’ (DfRem) originates from the understanding that decisions made during the design process may have a considerable effect upon the efficiency and effectiveness of the remanufacturing process. Much of the DfRem literature to date has focused upon the identification of technical DfRem factors (such as material choice or fastening methods), and the subsequent development of design methods and tools. However, the literature has overlooked how DfRem practices may be integrated into a company design process, and has not considered the operational factors that may influence DfRem integration decision-making and practice. This thesis presents the findings from industrial case study research with three original equipment manufacturers (OEMs) from the UK mechanical industry sector. Through observation and interviews with designers, design management, and aftermarket and remanufacturing management, the research has indentified significant external and internal operational factors that influence DfRem integration, including management commitment, OEM-remanufacturer relationships and designer motivation. The findings led to the development of a ‘DfRem integration network model’ which maps the identified relationships between the various operational factors, providing practitioners with an enhanced understanding of DfRem integration into the design process, and a portfolio of practical steps towards more remanufacturable products and improved remanufacturing services.

Chapter 1: Introduction

This first chapter of the thesis will introduce the topic of remanufacture, and provide details of both the remanufacturing process and its role in industry today. The chapter will also introduce the concept of 'design for remanufacture', and present the particular aim and objectives of this research study. Finally, this chapter will outline the structure of the following chapters of the thesis.

1.1. What is 'Remanufacture'?

1.1.1 Background: a product's 'end-of-life'

It is now common knowledge that the world's resources are becoming increasingly scarce and the country's landfill sites are rapidly reaching capacity. Global warming is largely accepted as a real threat, not only to our way of life, but also the future of our planet. It is also widely acknowledged that manufacturers and product designers must consider the full lifecycle of their products. Manufactured products, from machinery to mobile phones, to textiles and packaging, all have an environmental impact throughout their lifecycles: emissions from manufacture, energy consumption during use, valuable minerals lost in disposal…and so on.

These lifecycle considerations include the product end-of-life phase, when the product no longer meets the requirements of the customer and is therefore discarded, either to landfill or otherwise. Typically, this stage in a product's life has not been of concern to the average designer. As far as designers are concerned, responsibility traditionally ends once the product has reached the market. However, as landfill space becomes scarcer and as the cost of product disposal increases, manufacturers are forced to seek alternative, more sustainable end-of-life strategies for their products. Current legislation such as the End of Life Vehicle (ELV) Directive and Waste Electrical and Electronic Equipment (WEEE) Directive (which aim to increase the proportion of waste material which is recovered at a product's end-of-life, and put this responsibility in the producer's hands), is already encouraging companies to think more sustainably, and such legislation is likely to become more stringent in the future.

1.1.2 The remanufacturing process

One product end-of-life strategy is remanufacture, the process of returning a used product (referred to as 'cores' in the industry) to original equipment manufacturer (OEM) specifications or better, with a warranty to match (Ijomah, 2002).The process includes sorting, inspection, disassembly, cleaning, reprocessing and reassembly (see Figure 1). The sequence of these activities will vary with different products and remanufacturers (Sundin, 2004). Parts which cannot be brought back to original specification are replaced, which means that the final remanufactured product may be a combination of new and reused parts. Remanufacture is different from other, similar end-of-life treatments such as refurbish and repair due to the quality of the final product. When a used product is refurbished, all worn components will only be returned to a *workable* condition, yet will not be of equal quality i.e. expected to last as long as a newly manufactured equivalent. Repairing requires even less work content, and costs less, as only major components will be returned to a working condition, i.e. the correction of specified faults (King et al., 2006). Again, repaired products may be priced lower than remanufactured products, but will not have a warranty equal to that of a newly manufactured equivalent. The similarity of the terms 'remanufacture, recondition, repair', and the relatively small technical differences between their definitions, often means that such terms are found confusing and used interchangeably (Charter and Gray, 2008). Because remanufacture is the highest quality of the product reuse options (see Figure 2), this confusion over terms may have a detrimental effect on customers' perceptions of the process and the value of remanufactured goods.

The concept of product reuse is certainly not new, and remanufacturing specifically has become an increasingly prominent industrial activity since the Second World War, particularly in the United States. Historically the remanufacturing industry has primarily consisted of 'third party' remanufacturers, however OEMs have also increasingly adopted the practice, either by remanufacturing their own products or passing the responsibility to a contractor. However, it was not until the late 1970s, early 1980s that interest in remanufacturing as an academic research topic began to emerge, with Robert Lund's original studies of the remanufacturing industry (Lund and Hauser, 2010). This slow uptake of academic interest means that there is still much to learn about the subject. Today, however, interest in remanufacturing is rapidly increasing due to a greater understanding of its advantages and potentially important role in our changing society.

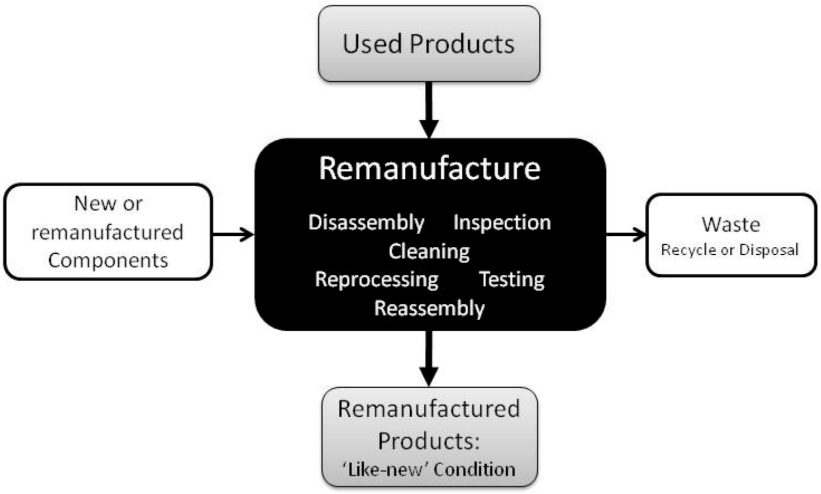


Figure 1: An illustration of a generic remanufacturing process.

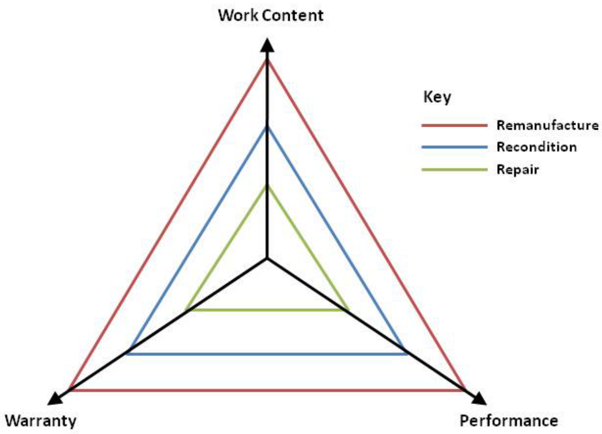


Figure 2: Comparison of remanufacture, recondition and repair (Ijomah, 2002).

1.1.3 Remanufacturing advantages: environmental

Greater public and government awareness and concern of environmental issues in general has increased the pressure to find sustainable ways of managing our consumer culture. Remanufacturing is often considered to be an environmentally responsible end-of-life solution, diverting products from landfill by creating multiple lifecycles. Considering the UK alone, landfill is becoming an increasing problem not only because of the adverse environmental effects of leachate (released liquid containing environmentally harmful substances), but also due to our dwindling landfill capacity. The Local Government Association predicted in 2007 that the UK could run out of landfill space as soon as the year 2016 (LGA, 2007). Between 1980 and 1997, municipal waste in 'Organisation for Economic Co-operation and Development' (OECD) countries increased by 40%, and it is predicted to rise by another 40% by 2020 (OECD, 2001). As a general rule, the more affluent consumers become the more waste they will generate, so as the world's developing nations progress, the global waste problem can only be expected to increase. Remanufacturing could be just one way of helping to alleviate this global problem.

In addition, many of the processes associated with new manufacture, such as raw material extraction, are not required in remanufacturing (Nasr and Thurston, 2006). The energy used to carry out these processes is therefore saved, as is much the (increasingly scarce) raw material requirements of new manufacturing (Lund, 1984). Remanufacturing typically requires 15% of the energy required to manufacture an equivalent product (Giuntini and Gaudette, 2003). A reduction in processing requirements can also lead to considerable emissions savings as well. A 2009 survey of the UK remanufacturing industry found that automotive remanufacturing, for example, saves over 40000 tonnes of CO_2 in this country alone (Chapman et al., 2009). Lindahl et al. (2006) carried out a study to determine exactly how environmentally preferable remanufacture is when compared to recycling and 'new manufacture', by carrying out life cycle analysis for various products under the three scenarios. The emissions produced in new manufacture were up to 60 times higher than that of remanufacture, and all of the remanufactured products analysed had significant savings in materials and/or energy when compared to new manufacture and recycling.

In 2001 the OECD predicted that their manufacturing waste would continue to increase into the next decade, however at a lower volume per manufacturing output as plants become more efficient and manufacturers become less resource dependent (OECD, 2001). It could be said that increased remanufacturing activity could contribute to this decrease in waste-output ratio.

1.1.4 Remanufacturing advantages: legislation

'Extended producer responsibility' (EPR) is a policy strategy that ensures the original producer of a product retains full ownership and responsibility for that product in terms of liability, financial, physical and informative responsibility (van Rossem et al., 2006). This means that the producer is responsible for the waste disposal costs related to that product. The producer may also take responsibility for the physical disposal of the product, or pass this on to a contracted third party. The concept of EPR has in recent years resulted in several environmental directives being passed in the UK, for example, the WEEE (waste electrical and electronic equipment) Directive (European Parliament and Council, 2003) and the ELV (end-of-life vehicle) Directive (European Parliament and Council, 2000). Despite these progressions, the UK is still under criticism for failing to fully implement individual producer responsibility (as opposed to collective), as specified in the European

WEEE Directive (IPR Works, 2007). This is an indication that such legislation has the capacity to become tougher in the years to come.

Other recent developments in this field include standards such as Germany's VDI 2243 (VDI, 2002) and the UK's BS 8887 (British Standards Institution, 2010). The key contribution of BS 8887 is an official list of end-of-life processing terminology, including repair, recondition and remanufacture. This clarification of the quality of remanufactured goods is intended to increase overall confidence in the process and resultant products, from both industry and consumers. Furthermore, the WEEE Directive and other legislation do not currently discuss remanufacture in their text. These standards may be a stepping stone to rectifying this problem.

In addition to legislation and standards, the cost of conventional landfill disposal is constantly increasing. At time of writing, UK landfill tax is currently £64/tonne for active waste and is set to increase to £80/tonne in 2014 (Biffa, 2010). This government deterrent to landfill disposal could also incentivise remanufacturing activity.

1.1.5 Remanufacturing advantages: profitability

Arguably the greatest advantage of remanufacturing, from an industry perspective, is the economic incentive. In a series of case studies with UK mechanical and electromechanical manufacturers, the most preferable reason given for deciding to remanufacture was found to be profit, followed by environmental legislation. Not surprisingly, none of the companies surveyed would carry out remanufacture simply to reduce environmental impact (Ijomah et al., 2007b). Instead, many companies have decided to remanufacture simply because it has been found to be a profitable business venture (Nasr et al. 1998) in (Guide, 2000).

As remanufactured products are reused at component level (as opposed to raw material level), much of the 'intrinsic value' i.e. the energy and labour input of original manufacture is retained. This eliminates the need for many of the activities involved in new manufacture, such as raw material extraction and processing, as well as many of the processing involved in conventional recycling. As a result, remanufacturing costs are lower than that of new manufacture, typically by 40-65% (Giuntini and Gaudette, 2003). Clearly, if manufacturers are able to extend the life of their products, create multiple lifecycles and therefore introduce multiple revenue streams, as well as save money on labour, materials, energy and landfill taxes, they will in turn increase the overall profitability of each product they produce.

An OEM that remanufactures may also gain insight into the use-phase of its products, enabling design improvements which may improve customer satisfaction and potentially increase sales. When used products are returned to an OEM, design flaws can be noted and improved upon in later products, increasing customer satisfaction (Sundin et al., 2000). As remanufactured products can be priced lower than newly manufactured equivalents— typically 30-40% less— such companies can also offer their customers a much wider price range (Giuntini and Gaudette, 2003).

These financial and business incentives indicate that remanufacture is a strong candidate for many companies with waste reduction targets or ambitions. If remanufacture is profitable, the process requirements become an opportunity, not a burden on the organisation.

1.1.6 The remanufacturing industry today

Industry overview

In 2009 the Centre for Remanufacture and Reuse (CRR) conducted a survey of the UK remanufacturing industry (Chapman et al., 2009). From this survey 14 industry sectors were identified as either currently having a high remanufacturing value or having the potential to do so in the near future. Of these sectors, the most valuable at present were found to be ink and toner cartridges, automotive, off-road equipment and pumps and compressors, as shown in Figure 3. The survey determined the overall value of the remanufacturing and reuse industries in the UK to be £2.35 billion, of which about 50% can be attributed to remanufacturing specifically (Chapman et al., 2009).

In comparison, a 1996 survey by Robert Lund found the US remanufacturing industry to be around $53 billion, employing 480,000 (Giuntini and Gaudette, 2003). A 2001 survey found that the US spends $47 billion annually on remanufacturing, amounting to 0.4% GDP (Giuntini and Gaudette, 2003). Of course the relative size of the two countries should be taken into account. Chapman et al (2009) describe the UK remanufacturing industry as ‘healthy, but potentially vulnerable’ citing issues such as declining manufacturing activity, cheap products from overseas and high UK labour costs as threats to continued growth.

With the exception of ink cartridges, which undergo a very simple remanufacturing process, the most valuable remanufacturing sectors in the UK typically involve high-value and heavy-duty products: engine blocks, transmissions, pumps and so on. Industries identified as having high growth potential included off-road equipment and aerospace (Chapman et al., 2009).

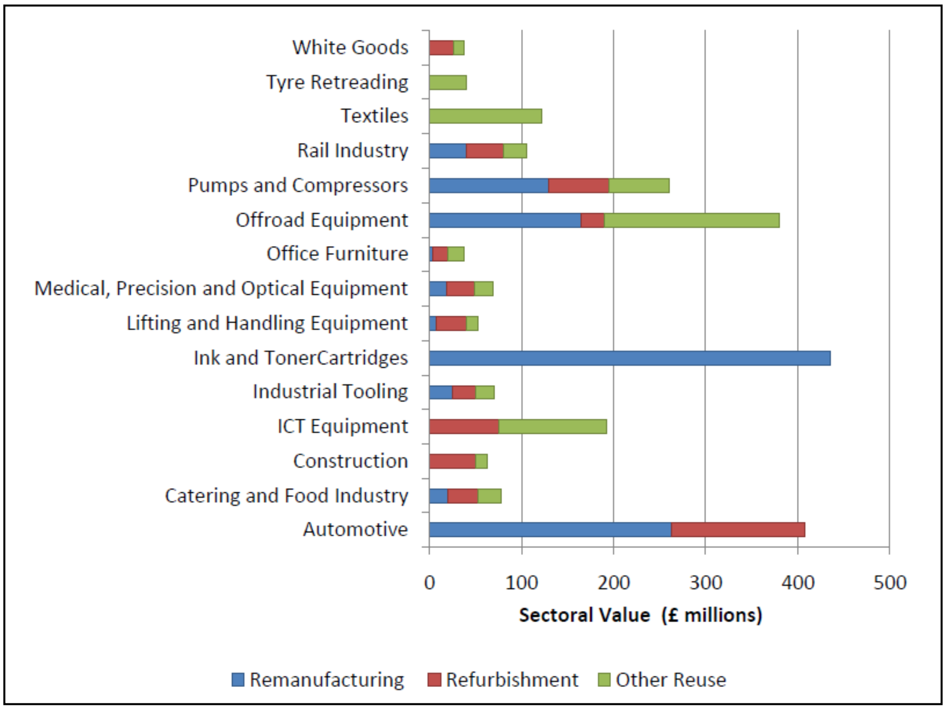


Figure 3: Estimated sectoral values for UK reuse and remanufacturing activities (Chapman et al., 2009).

1.5.2 Example: Xerox

However, as Figure 4 demonstrates, there are other, less conventional industries which also show potential for successful remanufacture such as medical equipment, office furniture and ICT equipment. Indeed, one of the most commonly cited remanufacturing success stories is the case of Xerox photocopiers (Ayres et al., 1997, Kerr and Ryan, 2001).

Xerox began a ‘take-back’ scheme in the early 1990s, for photocopiers which had been in use for 5 years or more, depending on the number of copies made by the machine (Charter and Gray, 2008). The used machines were then recycled and/or remanufactured, and by 2003 95% of Xerox waste was reused, saving around 175000 tonnes of waste materials. Around 25% of this output was from remanufacture (Charter and Gray, 2008). Remanufactured photocopiers can go through up to 7 lifecycles (Charter and Gray, 2008), and around 70-90% of the machine will be reused each time (Xerox, 2012). Remanufacture enables Xerox to reach new customers (those who cannot afford new products), reduce the company’s waste disposal and raw material requirements and promote a green company image (Parker, 2007).

In an interview for remanufacturing consultancy group Oakdene Hollins (Parker, 2007), a Xerox remanufacturing manager stated that the company has increasingly moved away from remanufacturing whole equipment, and is now more focused upon increasing component remanufacturing. Reasons given for this change included the cost of remanufacturing older models and the challenge of meeting modern energy consumption standards. The interviewee also cited several of the remanufacturing barriers and challenges Xerox face, including lack of public awareness, cost of logistics and conflicts with energy consumption and emissions requirements (Parker, 2007).

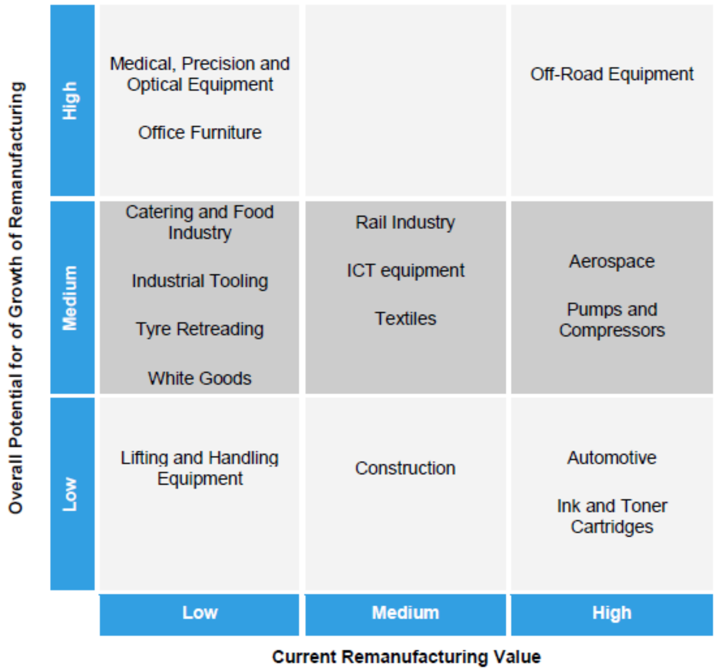


Figure 4: Current UK remanufacturing value and potential for growth (Chapman et al., 2009).

1.5.3 Caterpillar

Caterpillar is another classic example of successful remanufacturing. As a leading manufacturer of off-road equipment, Caterpillar products are much more traditional candidates for remanufacture, and the company has taken advantage of this fact.

Although Caterpillar first began remanufacturing its products as far back as 1972 (Charter and Gray, 2008), it has only been within the past twelve years or so that the company has established a remanufacturing service in the UK, under the ‘CAT Reman’ brand name (Parker, 2007). Today Caterpillar recycles and remanufactures over 50,000 tonnes of used products per year, amounting to over 2.2 million end-of-life units (Charter and Gray, 2008). The decision to remanufacture was primarily driven by customer demand, as Caterpillar’s customers often come from industries with high operating costs (for example the construction industry) (Parker, 2007).

Caterpillar encourage the return of cores by providing customers with a ‘core refund’: a partial discount when they return their used products. The rate of this refund will depend upon the condition of the returned product, as determined by a visual inspection (Caterpillar, 2012b). To qualify for a partial refund, the cores must have no visible cracks, no broken or welded components; and they must be fully assembled with no non-operational damage. The Caterpillar products typically remanufactured include cylinder packs, water pumps, engine components and transmissions. The remanufactured products are branded with the CAT Reman logo to provide competitive advantage over 3rd party remanufacturers (Charter and Gray, 2008), and sold at a price typically around 40-70% of a newly manufactured equivalent, despite CAT Reman products having an equal warranty (Caterpillar, 2012a).

Today CAT Reman is one of the fastest growing divisions of the whole Caterpillar company, with annual revenue of over $1 billion and annual growth at around 20% (Charter and Gray, 2008).

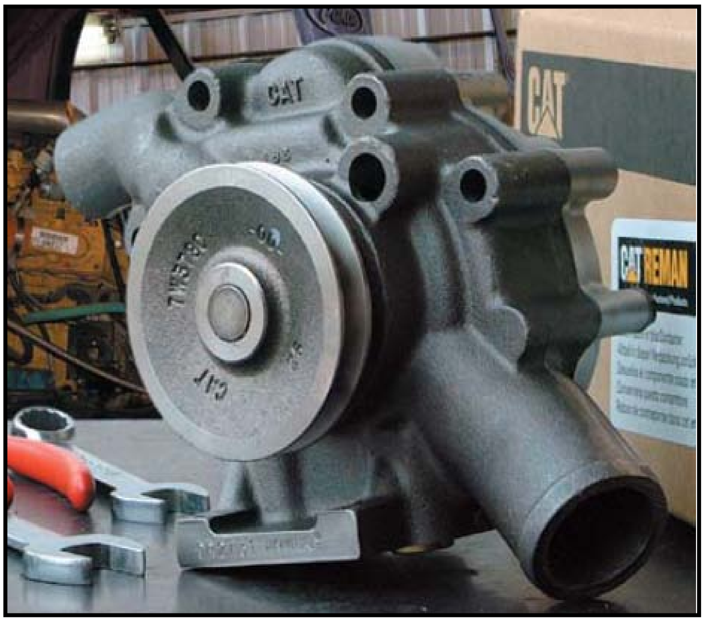


Figure 5: Caterpillar water pump

1.2. Design for Remanufacture

One particular research area in the field of remanufacture is the concept of ‘design for remanufacture’, or DfRem. It has been found that the remanufacturability of a product is dependent upon a variety of product features and characteristics including high customer demand, a reverse flow of cores and recoverable high-value parts (Ayres et al., 1997). The water pump shown in Figure 5 is a good example of a typically remanufacturable product: it has high value parts worth investing in and durable materials able to withstand both multiple lifecycles and the remanufacturing process itself. There is customer demand for remanufactured Caterpillar products and the company has devised a system for the return of used products to the remanufacturer.

It is also beneficial if the product is technologically stable (no expected rapid or drastic technological changes or innovations) and the demand for the product is not fashion-led. These factors will be discussed in greater detail in the Literature Review section of this thesis.

Whether a product can be easily remanufactured or not also greatly depends upon decisions made during the design process. (Sundin, 2004) has illustrated this relationship with the 'RemPro matrix' (Figure 6). As can be seen from the matrix, there are specific product properties that can have a positive effect upon specific remanufacturing steps. These properties, such as ease of access or ease of separation, are achieved through appropriate product design. Conversely, if these properties are overlooked at the design stage, this may have an adverse effect on the remanufacturability of the product. According to Ijomah et al (2007a) most of the technical barriers to remanufacturing have been found to be product design related. Remanufacturing steps such as disassembly and reprocessing cannot be carried out efficiently and effectively if the product has not been designed to accommodate them. Therefore, research outlined in Ijomah et al (2007a) resulted in the development of a 'robust' set of DfRem guidelines, practical advice for designing remanufacturability into a new product development. A selection of these guidelines have been summarised in Table 1.

REMANUFACTURING STEP / PRODUCT PROPERTY	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of identification	X		X	X			X
Ease of verification	X						
Ease of access	X	X	X		X		X
Ease of handling			X	X	X	X	
Ease of separation			X		X		
Ease of securing						X	
Ease of alignment						X	
Ease of stacking				X			
Ease of resistance		X	X		X	X	

Figure 6: The RemPro Matrix was developed by Sundin (2004) to illustrate the effects of different DfRem considerations upon the remanufacturing process.

One of the most commonly referred to examples of DfRem is Xerox photocopiers. By 2001, Xerox could claim that 100% of their newly developed products were designed with remanufacture taken into consideration, with the most significant design features being fewer parts for ease of disassembly and the adoption of a platform design model (Charter and Gray, 2008). ‘Platform design’, refers to when different products within a range are based upon the same base components, providing customer choice whilst reducing remanufacturing (and manufacturing) complexity (King and Burgess, 2005). In a study of Xerox photocopiers and the environmental impact of remanufacturing, Kerr and Ryan (2001) found that designing Xerox photocopiers for remanufacture had a positive impact upon both economic and environmental savings. However, the remanufacturability of Xerox products is still under threat by other design priorities: in an interview with remanufacturing management at Xerox, ‘design emphasis on DfA (design for assembly)’ was cited as a major barrier to successful remanufacture at the company (Parker, 2007).

1.3. Significance of DfRem Research

From the earliest stage, this research was focused upon the field of ‘design for remanufacture’, with a view to expanding DfRem knowledge, because it was found to be an important research area with scope for significant advancements. The importance of designing products for ease of remanufacture has been regularly emphasised in the literature, for example:

‘The largest gain in enhancing reusability and remanufacturability, and subsequent reduction of environmental impact, can be made in design, and particularly in the early stages of design.’ (Amezquita et al., 1995)

‘The significance of design-for-remanufacturing (DfRem) is that design is the stage that has the strongest influence on environmental impact and also sets the product’s capabilities.’ (Ijomah et al., 2007a)

Generally, if the design of the product improves the ease of remanufacture, the remanufacturing operation may become more profitable as a whole. Firstly the amount of waste may be reduced. For example, if the product can be disassembled without damage, a greater number of valuable parts may be retained. Similarly if the design is more durable, fewer products may be returned in an un-reusable state, meaning a greater retention of parts. Less waste means fewer new parts must be purchased and installed into the remanufactured product. Waste disposal costs are also reduced.

Secondly, design for remanufacture can improve the efficiency of the remanufacturing process. For example, if the product is designed for ease of disassembly, this step may take less time. If valuable components are clustered in easy to access areas, the product may not even require full disassembly before all remanufacturable parts have been salvaged.

Reducing waste and improving process efficiency will increase the profitability of remanufacture, making it a more viable and lucrative end-of-life option. However, it would appear that very few products today are consciously designed for remanufacture. Therefore, research into the product design-related requirements of remanufacture and how these can be achieved is a significant contribution to overall remanufacturing research. It was for this reason that ‘design for remanufacture’ was chosen as the overall topic for this research.

Although DfRem is becoming an increasingly distinct research subject, it is still often conflated with ‘design of for environment’ or ‘ecodesign’, and the literature review sections of many DfRem papers will reference ecodesign papers without making a distinction between the two. Ecodesign and its many synonyms refers to the development of low-environmental-impact products through considerations such as material choice, process choice, energy efficiency and increasingly reorienting social behaviour (Manzini and Vezzoli, 2008). Quite logically DfRem is often considered to be under the wide umbrella of environmental design considerations, because efficient and effective remanufacturing can often reduce a company’s environmental impact. Also, there is a crossover between DfRem guidelines and ecodesign guidelines, for example the reduction of hazardous materials. However, because the motivations behind DfRem and ecodesign are not exactly the same (remanufacturing is mainly driven by profit), it is the author’s view that findings from ecodesign research are not automatically inter-changeable with DfRem theory. Findings by Ijomah et al. (2007a) suggest that companies are very unlikely to remanufacture for environmental reasons alone, and companies surveyed rated profitability as the main incentive for their involvement in remanufacturing. Charter and Gray (2008) agree that this blurring of terminology is unhelpful:

‘This confusion of terminology may show merely a relaxed use of phrases but it may also demonstrate a misunderstanding of the specific concepts of Design for Remanufacture within the industry itself.’

In order that DfRem be better understood by both academia and industry, it is important that more DfRem-specific research is conducted, which will make a clear distinction between remanufacturing issues and environmental issues.

1.4. Research Aims and Objectives

Once the general theme of ‘design for remanufacture’ had been selected for this research, a specific aim and set of objectives were defined. DfRem research to date has primarily involved the development of design methods and tools that may be utilised to improve the remanufacturability of a product from a technical design perspective. The problems (in the authors view, based upon the literature review) with this limited approach to DfRem research will be discussed at various points throughout the thesis. Critically for this research, it was noted that there has been little consideration of how DfRem may be integrated into the design process of a company wishing to enhance the remanufacturability of its products. Furthermore, these previous studies appear to be conducted and reported with the assumption that the provision of such methods and tools alone is sufficient to ensure successful DfRem; no consideration appears to have been given to how other, less tangible factors can also have a significant impact, such as the *operational* factors concerning a design engineering team and a company design process. These factors can be defined as those that relate to the development of a remanufacturable product, as opposed to the physical characteristics of that product, e.g. the people and processes involved. Therefore, the overall aim of this research was:

'To gain an understanding of the operational factors that enable design for remanufacture (DfRem) to be better integrated into a company design process.'

To assist in achieving this aim, four objectives were also set:

1. Determine the external operational factors which influence the decision to design for remanufacture.
2. Determine the internal operational factors which influence DfRem integration into the design process.
3. Determine and map the relationships between the operational factors.
4. Present this new knowledge in a way that will contribute towards achievement of better DfRem integration, by enhancing its usefulness to an OEM design engineering team.

The aim of the research presented in this paper was to identify and explain the external operational factors the influence DfRem, and the internal operational factors that influence the integration of DfRem into a company's design process. 'External factors' refers to those factors which were identified as having or potentially having a direct and identifiable influence upon a company's decision to design for remanufacture in the first instance, i.e. 'kickstarting' integration. Understanding what external factors drive a company to design for remanufacture puts the discussion of integration into context. 'Internal factors' refers to the more specific factors relating to design engineering which were found to potentially influence the actual process of integrating DfRem into a company design process. These factors would be within the control of a design engineering team. Categorising the factors as 'internal' or 'external' was a useful lens from which to organise data, and formulate the final outcomes and practical recommendations that resulted from this research. However, due to organisational complexity it should be noted that the boundaries between these two distinctions was no always clear, and the degree of influence design engineering teams had over a factor was not tested in this research. Knowledge of operational factors, both external and internal will provide a systems view of how DfRem may be better integrated into an OEM design process.

The content of this thesis will address how this aim and objectives were met.

1.5. Thesis Structure

The structure of the thesis follows a narrative which describes the PhD journey, from early background research to data collection to validation and reflection of the research results.

Chapter 2: Literature Review

This chapter will discuss the current understanding of what DfRem means and what it involves, according to the literature. The state-of-the-art for DfRem research will be outlined in detail. As there is very little literature to be found on the subject of DfRem integration into the design process, this chapter will also discuss how similar findings from the field of ecodesign were used as a basis for this study.

Chapter 3: Research Design

This chapter will outline the characteristics of the research, including ontology and epistemology, then continue to present the selected research methodology (multiple case study, theory-building) in detail. This chapter will also discuss how the research findings would be validated.

This chapter also elaborates on the selected case study methodology by presenting the case study protocol: how companies were selected, the case study procedure and the case study protocol questions which were asked of both interviewees and the study as a whole throughout data collection. This chapter will also introduce in detail the three case study companies that participated in the research, and the format for the case study reports that improved the reliability of the information gathered from them.

Chapter 4: Research Findings, Operational Factors

This chapter begins to present the research findings, and is focused upon the first and second research objectives: identifying internal and external operational factors that influence DfRem integration. The chapter begins with within-case analysis results for each individual case study company and then moves on to a discussion of cross-case analysis where the results from each case study are compared and contrasted in search of patterns, common themes and greater meaning to the findings. The conclusive external and internal factors are presented.

Chapter 5: Research Findings, Mapping DfRem Integration

This chapter is focused upon the third and fourth research objectives and begins with a discussion of the significance of understanding the relationships between operational factors and why it was considered an essential component to the research. The chapter then goes on to outline in detail each of the relationships identified through case study analysis, and presents the resultant integration network model. The model is explained in detail before the chapter goes on to explain how it was validated with both industry and academia to ensure accuracy and usefulness. This discussion includes how the model could be accessed in the future.

Chapter 6: Discussion

This chapter provides an overall discussion of the research findings: the significance of the outcomes and the implications for both industry and academia. This discussion includes a detailed comparison with some of the literature presented in chapter 2 in order to establish what new knowledge has resulted from the research and what previous assertions have been questioned or built upon.

Chapter 7: Conclusions

This final chapter of the thesis will summarise the key outcomes of the research: its contributions to both knowledge and practice. The conclusions will also include a discussion of the research limitations and future research needs which have been identified as a result of this work.

1.6 Summary of Chapter 1

Chapter 1 has served as an introduction to the concept of remanufacture and ‘design for remanufacture’ (DfRem), and has explained why research in this field is of particular significance to both industry and global sustainability. The chapter has also introduced the overall theme of this research—DfRem integration factors— and the specific research aim and objectives. These were decided upon through findings from a literature review of DfRem state-of-the-art research, as discussed in the next chapter.

Chapter 2: Literature Review

Prior to and during data collection for this research, a review of the literature was conducted firstly to gain an understanding of the current state-of-the-art, and secondly to identify gaps in the knowledge which could influence the direction of the research. This chapter will provide an overview of previous research in DfRem and similar fields, and discuss the gaps in the literature which brought about the research aims and objectives.

2.1 Literature Review Scope

Approximately 150 journal and conference papers and books published between 1984 and 2012 were reviewed to gain an understanding of remanufacture and DfRem state-of-the-art, and to explore potential avenues that could influence the aim and objectives of this research. Of these resources, only 37 were specifically about designing products for increased remanufacturability, dating from 1995-2011. Clearly this is a relatively new and unexplored research topic. The remainder of papers studied for this review fell under one of the following categories:

- The remanufacturing process, its benefits, opportunities and challenges.
- End-of-life decision making in product design: when is remanufacture and DfRem appropriate?
- Other relevant 'DfX' literature which could highlight knowledge gaps: design for disassembly, design for manufacture and assembly, design for recycling, design for environment. Particular attention was paid to 'design for environment' (ecodesign, sustainable design, green design…) because in the literature remanufacture is often associated with environmental concerns.
- Design knowledge: the nature of design knowledge, knowledge capture and transfer in product design. What DfRem knowledge do designers require and how can this knowledge be delivered?
- Operational factors in product design, in particular those influencing ecodesign integration.

2.2. Understanding of DfRem

2.2.1 Definitions of DfRem

Very early studies of remanufacturing pay some attention to the properties of a typically remanufacturable product, such as durable cores capable of non-destructive disassembly, technological stability and the capacity for product or system upgrade (Lund, 1984). However, the idea that a product could be specifically designed to facilitate effective remanufacture is not proposed in these early papers.

The concept of 'design for remanufacture' as a design activity has arisen from the recognition that many of the technical barriers to remanufacture can be traced back to the product development stage (Ijomah et al., 2007a). Remanufacturing steps such as disassembly and cleaning cannot be carried out efficiently and effectively if the product has not been designed to accommodate them. So what exactly is DfRem? What does it involve? From a top-level perspective, there have been a variety of definitions presented in the literature, for example:

"Product design that facilitates any of the steps involved in remanufacture..." (Shu and Flowers, 1999)

"Considering the product strategy (marketing, reverse logistics) and the detail engineering of the product in terms of remanufacture." (Nasr and Thurston, 2006)

"A combination of design processes whereby an item is designed to facilitate remanufacture." (Charter and Gray, 2008)

These descriptions provide a general overview of what DfRem is. Obviously the goal of DfRem is to enhance remanufacturability. To do this, a designer must actively consider each remanufacturing step, or issue, and how the design will impact upon them. The literature regards DfRem as a distinct design task; as the name would suggest, it is most often viewed as part of the concurrent engineering concept of 'design for X' (DfX), in this case X being remanufacture.

However, looking deeper, it would appear that from many researchers' perspectives DfRem is not simply one 'DfX' but in fact a number of different factors to be considered simultaneously. Sundin (2004) identified the relationships between different product properties and specific remanufacturing steps, as illustrated in the 'RemPro Matrix' (Figure 6). These different factors, such as ease of access or ease of separation, are achieved through appropriate product design. Conversely, if these properties are overlooked at the design stage, this may have an adverse effect on the remanufacturability of the product. The RemPro Matrix would therefore suggest that DfRem is not a single, homogenous task but actually a collection of many tasks or considerations whose prioritisation will differ depending on the processing needs of the product.

Similarly, Charter and Gray (2008) have described DfRem as a series of DfX activities: design for core collection, eco-design, design for disassembly, design for multiple lifecycles, design for upgrade, and design for evaluation. Although worded and explained differently from the RemPro matrix, the overall goal remains the same: to facilitate the entire remanufacturing operation, through a number of tasks or considerations. Clearly, taking all these factors into consideration suggests DfRem must be a thorough, dedicated and perhaps lengthy task in order to be effective. Zwolinski et al. (2006) have criticised this 'DfX' frame of mind as it assumes that *'the remanufacturing process (and the business associated with) is perfectly known'*. Specifying that designers consider each remanufacturing aspect individually may in theory be the most effective method, but in reality may be an overly daunting and complex task. Nevertheless, the design for remanufacture task is most commonly outlined in these terms.

The next stage in understanding DfRem is to ask *how* one designs for remanufacture. This is a difficult question to answer as what enhances remanufacturability for one product, or one process, may differ from another. Therefore, much of the DfRem guidance offered in literature is fairly general. However, some researchers have attempted to compile lists of guidelines that could steer a design towards remanufacturability. Other researchers, whilst not explicitly offering a list of guidelines have offered similar guidance throughout their discussions. These guidelines will usually refer to either the materials of the product, its structure / geometry or fastening and joining methods. They may also be linked to a particular remanufacturing concern, such as disassembly or durability. Such guidelines provide a clearer picture of what it means to design for remanufacture and consequently what properties a remanufacturable product should have. A selection of these guidelines is presented in Table 1.

Table 1: A selection of DfRem guidelines, from various sources in the literature.

Guideline	Comment	Category	Process Affected	Reference(s)
Design for Disassembly				
Avoid permanent fastening methods.	These cannot be disassembled non-destructively.	Fastening and joining methods.	Disassembly, reprocessing	Amezquita et al.(1995); WaxRDC (2009)
Use assembly methods that allow disassembly to at least to the point that remanufacturable components can be accessed.	Further disassembly may not be economically viable.	Assembly methods.	Disassembly, reprocessing, cleaning	Ijomah et al. (2007a)
Standardise fasteners.	Reduce disassembly complexity (time etc).	Fastening and joining methods.	Disassembly	Ijomah et al.(2007a); Shu and Flowers (1999); Amezquita et al.(1995); Boothroyd and Alting (1992)
Minimise number of joints/ fasteners.	Reduce disassembly work.	Fastening and joining methods.	Disassembly	Ijomah et al.(2007a); Shu and Flowers (1999); Boothroyd and Alting (1992)
Design for Cleaning				
Use corrosion resistant/ durable materials	They will survive the cleaning process i.e. Abrasion, chemicals, heat.	Materials	Cleaning	Ijomah et al.(2007a); Boothroyd and Alting (1992)
Smooth but wear resistant product surfaces.	Easier to clean (dirt doesn't get clogged etc), easier to clean without damage e.g. Through abrasion.	Product structure	Cleaning	Ijomah et al. (2007a); Shu and Flowers (1999)
Use durable material markers	For example stickers would wash off	Materials	Inspection, cleaning	Ijomah (2009)
Design for Durability				
Use durable materials for components desired for reuse.	Suitable for long/ multiple product lifecycles; less likely to be damaged during disassembly	Materials	Disassembly, reprocessing	Ijomah et al. (2007a); Shu and Flowers (1999); Charter and Gray (2008)
Designed to minimise damage incurred during transit	If they have an awkward geometry, products could get damaged on their way to remanufacture, and no longer be viable	Product structure	Transit, remanufacture	Shu and Flowers (1999); Boothroyd and Alting (1992)
Design for Upgrade				
Use high value-added components with stable designs	When the product is retired, valuable parts will not be obsolete	Product structure	Reprocessing	Ferrer (2001)
design for optimum life	Let customer return when full value has been used in product, yet is still suitable for reman/ upgrade.	Product structure	Reprocessing	Charter and Gray (2008)
Design for Inspection				
Identify component material e.g. markings in moulding	Materials can easily be distinguished from one another.	Materials	Inspection, reprocessing	Ijomah et al. (2007a); WaxRDC (2009); Ijomah (2009)
Include sacrificial parts	Parts that would show obvious wear and indicate the condition of the product.	Product structure	Inspection	Charter and Gray (2008)

However, there are still a number of problems and issues that these guidelines do not sufficiently address, such as:

- Conflicts with other design interests: following guidelines which enhance remanufacturability may compromise other important design issues such as cost or environmental performance.
- Subjectivity: generic guidelines do not account for the fact that every product / project / company is different, with different needs, capabilities, customers and so on.
- Guidelines customisation: following on from the previous point, the literature on DfRem guidelines to date has not adequately addressed how companies may customize the generic guidelines to meet their specific requirements.

There has however been some relevant research in the field of design for environment that has attempted to address similar problems. Luttropp and Lagerstedt (2005) noted that very detailed design guidelines ran the risk of becoming too time-consuming and too product specific. Their solution, the 'Ten Golden Rules' is a set of very general ecodesign guidelines (such as 'promote repair and upgrading' and 'promote long life' which can then be customised and expanded upon by individual companies to better suit their products and specific company needs. Conversely, Vezzoli and Sciama (2006) argued the need for more detailed, product-specific guidelines, and have developed a method for determining such guidelines which are customised based upon the results of lifecycle analysis (LCA).

2.2.2 Participants in DfRem

The present understanding of DfRem (as presented in the literature) also includes the circumstances that enable this design activity to take place. Who should design for remanufacture, and why? Firstly, some researchers have felt it important to stress that not all products are suitable for remanufacture, either because it is not the most cost effective or environmentally preferable option (Kerr and Ryan (2001); Shu and Flowers (1999); King and Gu (2010); King and Barker (2007)). Product end-of-life decision making is a topic outwith the scope of this research. For most DfRem research, it can be assumed that remanufacture has already been selected as the preferable end-of-life treatment for the product, and/or is already taking place. A company is considered a suitable candidate for remanufacture (and therefore DfRem) when its products possess certain qualities:

- A reverse flow of used products i.e. a means for collecting cores and returning them to the remanufacturer (Lund (1984); Charter and Gray (2008); Ayres et al (1997)).
- Customer demand for the remanufactured product (Ayres et al., 1997).
- High value, durable parts which are economically worth the investment and able to withstand multiple lifecycles (Ayres et al., 1997, Charter and Gray, 2008).

- Technological stability i.e. products will not become obsolete before they may be remanufactured and re-sold (Lund, 1984, Srivastava, 2007).
- Potential for product upgrade, to ensure remanufactured products are technologically up-to-date (Shu and Flowers, 1999).

Mechanical / electromechanical products such as automotive components and off-road equipment often meet these requirements, as is reflected in the high value of these sectors in the UK remanufacturing industry (Chapman et al., 2009). Being of high value and high durability in particular, it is these products that are most often associated with intrinsic remanufacturability, because these characteristics often mean fewer barriers to a cost-effective remanufacturing process. However, many other successful remanufacturing operations exist for products that meet other significant criteria. For example, ink cartridges are successfully remanufactured due to high customer demand for low-cost alternatives to new manufacture, and Xerox invest in remanufacturing because the company's product-service system business model (discussed below) leads to an effective reverse flow of used products.

As well as product type, there has also been some consideration of the kinds of companies that would benefit from DfRem. Lund (1984) states that there are three possible remanufacturing scenarios:

- OEM (original equipment manufacturer) remanufacturing, when the original producer is also responsible for the remanufacture of its used products.
- Contract remanufacturing, when a remanufacturer is under contract from the OEM that continues to own the product.
- Independent, 3rd party remanufacturers that buy used products to remanufacture and resell. These remanufacturers have no connection with an OEM.

In much of the literature, it is only the first scenario- OEM remanufacturing- that is discussed as a feasible environment for DfRem (Amezquita et al., 1995, Bras, 2007, Charter and Gray, 2008, McIntosh and Bras, 1998). Indeed, the most common case study examples of DfRem used in the literature are OEMs such as Xerox, Caterpillar and Kodak. Common sense would explain why an OEM would have no desire to enhance the remanufacturability of a product simply to benefit an independent remanufacturer. In fact, it is not uncommon for an OEM to deliberately hinder remanufacture through either design or their own collection schemes in order to stifle this kind of activity, which is viewed as competition for their own new products (Hammond et al., 1998, Matsumoto et al., 2010, Parkinson and Thompson, 2003). However, if the OEM is directly involved in the remanufacture of its products, the following benefits may be gained, if the company were to choose to engage in DfRem:

- Improved efficiency of existing remanufacturing activity e.g. reduced material waste or reduced disassembly times, resulting in greater profitability of the operation.
- Or, in theory at least, preparation for future legislative changes that will render end-of-life responsibility a necessity. The products designed today will be the waste of tomorrow, and a company that plans ahead could obtain competitive advantage.

Seitz (2007) carried out a study of automotive OEM incentives to remanufacture, and found that their reasons provided good justification for design for remanufacture. The study questioned the most commonly cited remanufacturing incentives: ethics (environment), legislation and profit, which Seitz did not feel were substantiated by sufficient empirical evidence. The case study findings concluded that automotive OEMs did not consider these factors key to their decision to remanufacture, and instead would remanufacture to ensure there was a supply of spare parts that would meet customer's demands for low prices, and meet the company's warranty obligations. OEMs will also remanufacture to prevent independents from retrieving cores and potentially damaging OEM brand reputation. Seitz argued that these reasons were stronger incentives for an OEM to design for remanufacture than those traditionally cited.

In (Sundin et al., 2000, Sundin and Bras, 2005, Sundin et al., 2009), the opportunity for DfRem within a 'product-service system' business model is discussed. Product-service systems is an emerging marketing concept in which the OEM will retain ownership of the physical product and instead sell the service that product offers. For example, a photocopier manufacture may charge customers per copy rather than charging a one-off amount for the equipment. That OEM would then be responsible for the maintenance and disposal of the product. This way the customer benefits from reduced responsibility whilst the OEM can benefit from the reuse of components, for instance through remanufacturing. The referenced authors have therefore made an assertion that product-service systems and DfRem go hand in hand: an OEM involved in service selling would have every incentive to enhance remanufacturability through design, as a means of extending a physical product's lifecycle and therefore reducing manufacturing requirements, which are no longer the focus of a product-service system's business activities. Mont et al (2006) demonstrate design for remanufacture and product service systems with a case study of a baby pram and found the strategy to be financially feasible, albeit with high start-up investment.

Alongside the discussion about who is suited to DfRem, the literature also provides some indication of the barriers and complications such a company may face despite the potential benefits of carrying out DfRem. Firstly, at present, industry does not fully appreciate the benefits of remanufacture and DfRem, and so it is not a priority issue to the average designer. Most OEMs will primarily focus upon the product's production and use phases (Charter and Gray, 2008, Seitz and Wells, 2006). Furthermore, researchers such as Shu and Flowers (1999) have found that some DfRem principles are in direct conflict with prioritised issues such as manufacture and assembly. As long as this is the case, DfRem will be viewed as less valuable in terms of time and cost. As well as DfRem being viewed as unnecessary, there is apparently a lack of DfRem awareness amongst designers (Charter and Gray, 2008, Ijomah et al., 2007a). Bras and McIntosh (1999) say that '*remanufacture presents a fundamentally new set of challenges that producers are not prepared to deal with'*. Furthermore, the common confusion around the definition of remanufacturing (Charter and Gray, 2008, Ijomah et al., 2004) could mean that a company remanufactures without even knowing it, missing the opportunity to design for enhanced remanufacturability.

To summarise, DfRem is considered to be a distinct design activity that involves the consideration of a variety of design issues relating to remanufacture. DfRem could involve making decisions such as standardising parts or selecting a more durable material to optimise the remanufacturing process. It is most likely to occur when the OEM is responsible for remanufacture, either due to environmental, legislative or economic reasons, or as a means of supplying spare parts. However, this simplified view should not overlook the challenges and barriers, as mentioned in the literature, that such 'ideal candidates' may face.

2.3. DfRem Research State of the Art

2.3.1 Trends in DfRem research topics

Much of the DfRem research published to date has involved the investigation of technical remanufacturing problems associated with product design, and the subsequent development of design methods and tools that are designed to alleviate these problems at the product development stage. A summary of significant DfRem methods and tools presented in the literature is displayed in Table 2. Many of the design methods and tools are presented in the form of mathematical models and software tools, others are designed as reference material to assess remanufacturability, and others are intended to assist in decision-making or prioritisation.

Today, these methods and tools remain largely within the academic realm: it is difficult to find any evidence of them being utilised in industry today (Nasr and Thurston, 2006). Part of the reason may be that OEMs will develop their own in-house methods and tools for activities such as DfRem, and may be reluctant to share knowledge of these with the outside world for competitive reasons (Ijomah et al., 2007a). Also, as can be seen in Table 2, three recurring issues are the complexity of these academic design methods and tools, their lack of lifecycle thinking and the fact that most of these aids are only suitable for application late in the design process, when most major decisions have already been made and design changes are more difficult to make.

Another trend in DfRem research is the proposed use of existing product design concepts considered relevant to the enhancement of remanufacturability. A summary of these suggestions is presented in Table 3. The advantage of using established, industry-recognised methods, such as modularisation and QFD (Quality Function Deployment), is their familiarity: the designer may already be using these tools / methods or have understanding and experience of them, making DfRem integration much simpler. Also, these methods have other widely appreciated benefits outwith the interests of remanufacture, for example platform design is most commonly employed to reduce manufacturing costs and simplify the product development process. However, as these approaches have not been developed for DfRem purposes, they may not provide holistic assistance to improving the remanufacturability of products. Also, many are simply concepts and do not actually inform the designer, or provide the designer with guidance as to how DfRem may be carried out.

Due to the fact that the concept of DfRem only appeared in the literature as recently as 15 years ago, it is difficult to identify any clear changes in trends over time. However, it is interesting to note an apparent shift in perspective over the two decades. Whilst earlier developments focused upon finding technical, more quantitative solutions to the DfRem problem, for example Bras and Hammond's (1996) DfRem metrics; recent research is more focused upon suggesting familiar design methods and improving the qualitative guidance provided to designers, for example King and Burgess' (2005) platform design method and Ijomah et al.'s (2007a) robust DfRem guidelines. This change in direction could be due to the widely recognised belief that DfRem (or any significant 'DfX') is most effective when implemented early in the design process, when fewer decisions have been made yet less technical data is available (Amezquita et al., 1995, Zwolinski et al., 2006).

2.3.2 Trends in DfRem research demographics and methodology

Considering the demographics of DfRem research, there has been a clear shift across the Atlantic in recent years. DfRem research in the 1990s and early 2000s was most often carried out in USA or Canada, where remanufacturing has been established for the longest period of time. However, research from the past eight to ten years is more likely to have been carried out in European countries such as Sweden, France or the UK. This change in demographic coincides with an increase in the number of papers concerning the environmental impact of remanufacturing, which in turn coincides with the introduction of stricter environmental legislation across Europe.

Another theme worth considering under DfRem research trends is the methodologies used by previous researchers. Thirty seven papers presenting DfRem research findings were examined for information on adopted methodologies, the industry sector analysed in the study, and any products being used as case study examples. Although many authors did not specify what methodology was utilised to arrive at their findings, it would appear that case studies are a popular choice (see Table 4 and Figure 7). This may be due to the fact that DfRem is a relatively new and unexplored subject and case studies are considered an appropriate choice when there is little previous knowledge in the subject area (Eisenhardt, 1989, Yin, 2009). However, some of the earliest DfRem papers, from 1995 and 1996, adopted a more quantitative, survey approach (Amezquita et al., 1995, Bras and Hammond, 1996).

Considering industry sector and case examples (see Table 4 and Figure 8), much research has been done from a generic standpoint. However it is interesting to note the frequency of research and examples from the electrical and electronic equipment (EEE) sector. This grouping included products such as washing machines, disposable cameras and photocopiers. However, these products do not always match the traditional definition of a remanufacturable product: high value parts and durable materials. Many of the products studied in these papers are more likely to be reconditioned or recycled at the end of their life in use, and therefore are not the most obvious choice for a remanufacturing paper. The reason for these choices may be due to the recent attention to consumer waste that has been drawn in by legislation such as the WEEE Directive, and also because such products are being viewed as 'up and coming' in the remanufacturing industry and academia, and so may play a more prominent role in the future when skills, knowledge and technologies have improved (Brent and Steinhilper, 2004). However, it could be argued that in the present time, case studies of mechanical/ electromechanical are most relevant. Most of the discussion around EEE products concerns the initial decision of whether to remanufacture or not. However, as it has already been established that mechanical products, such as automotive components, are often suitable for remanufacture (Steinhilper, 2001), the discussion here has now moved towards how the process may become more efficient. This is when DfRem becomes of primary concern.

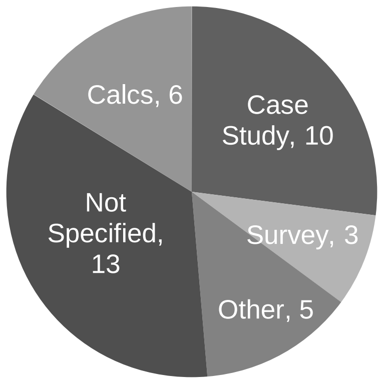


Figure 7: The methodologies adopted in previous DfRem literature.

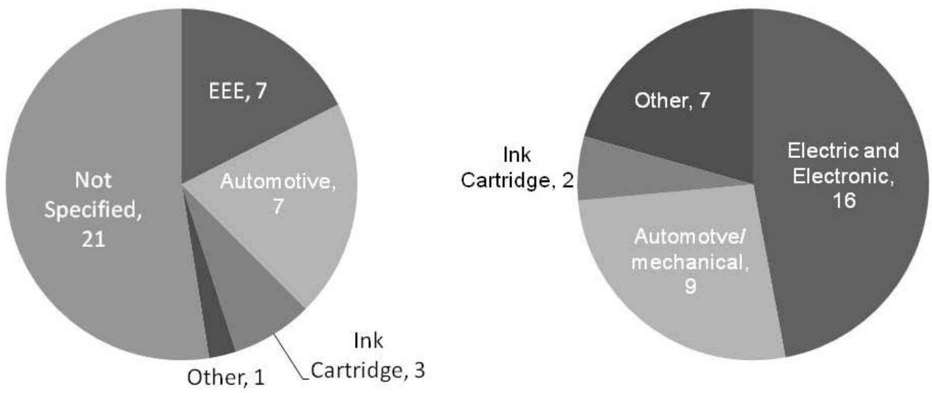


Figure 8: Industry sectors studied in the DfRem literature (left) and case study examples presented in the DfRem literature (right)

Table 2: Summary of DfRem design methods and tools found in the literature.

Approach	Author (s)	Format	Style	Key Purpose	Design Stage	Advantages	Disadvantages	Use in Industry
DfRem metrics	Bras and Hammond (1996) Amezquita et al. (1995)	Calculations / software	Quantitative	Assess remanufacturability	Detail	• Process oriented • Familiar concept (DfMA)	• Complex. • Retrospective. • No guidance.	No
Fastening and joining selection	Shu and Flowers (1999)	Calculations / software	Quantitative	Selection of most economical joining method	Detail	• Lifecycle thinking	• Complex. • Not holistic.	No
RemPro matrix	Sundin (2004)	Reference	Qualitative	Guidance, prioritisation of issues	Concept development	• Simple • Offers guidance	• Subjective. • No guidance.	No
REPRO2	Zwolinski et al. (2006); Zwolinski and Brissaud (2008); Gehin et al. (2008)	Software	Qualitative/ quantitative	Decision making, providing past examples	Concept generation	• Early in design process • Does not require extensive knowledge • Offers guidance	• Subjective.	No
DfRem guidelines	Ijomah et al. (2007b)b; Ijomah (2009)	Reference	Qualitative	Guidance	Concept generation	• Simple • Offers guidance	• Subjective. • Lack lifecycle thinking.	Unknown
DfRem metrics	Willems and Dewulf (2008)	Calculations / software	Quantitative	Assess remanufacturability, suggest improvements	Detail/ redesign	• Lifecycle thinking. • Offers guidance	• Complex. • Retrospective.	No
Hierarchical decision model	Lee et al. (2010)	Calculations	Quantitative	Design of product architecture for most profitable disassembly	Embodiment	• Lifecycle thinking	• Not holistic	No

Energy comparison tool	Sutherland et al. (2008)	Calculations	Quantitative	Compare manufacture and remanufacture energy usage	Detail	• Lifecycle thinking	• Not holistic • No guidance	No
Component reliability assessment	Zhang et al. (2010)	Calculations	Quantitative	Remanufacturing strategy decision-making	Embodiment	• Customer focused • Process oriented	• Not holistic • No guidance	No

Table 3: Summary of recommended design concepts suited to DfRem.

Approach	Author (s)	Format	Style	Key Purpose	Design Stage	Advantages	Disadvantages	Use in Industry
Modularisation	Ishii et al. (1994); Kimura et al. (2001)	Concept	Qual	*Traditional:* improve manufacturing efficiency. *Reman:* ease of disassembly.	Concept develop.	• Familiar concept.	• Not holistic. • No guidance.	Yes
FMEA	Lam et al. (2000); Sherwood and Shu (2000)	Paper/ software	Quant	*Traditional:* prioritise and prevent product failure. *Reman:* reduce waste in the remanufacturing process.	Concept develop, redesign	• Familiar concept. • Lifecycle thinking. • Process oriented.	• Not holistic. • Reliant on reman-OEM feedback. • No guidance.	Yes
Platform design	King and Burgess (2005)	Concept	Qual	*Traditional:* reduce manufacturing costs and retain customer choice. *Reman:* simplify process organisation.	Concept develop.	• Familiar concept. • Lifecycle thinking.	• Not holistic. • No guidance.	Yes
Active disassembly	Chiodo and Ijomah (2009)	Concept	Qual	Efficient disassembly.	Concept develop, detail	• Process oriented.	• Not holistic.	No
Design for environment tools	Pigosso et al. (2009)	Various	Varies	Improve environmental performance.	Various	• Lifecycle thinking.	• Not holistic. • Complex.	No
QFD	Yuksel (2010)	Paper/ software	Quant/ qual	*Traditional:* consider 'voice of the customer' to meet their needs. *Reman:* consider 'voice of the remanufacturer'.	Concept develop.	• Familiar concept. • Process oriented.	• Reliant on reman-OEM communication.	Yes

Table 4: Summary of DfRem research methodologies.

Approach	Author (s)	Methodology	Industry Sector	Perspective
DfRem metrics	Bras and Hammond (1996) Amezquita et al. (1995)	Survey	Unknown	Remanufacturer
Fastening and joining selection	Shu and Flowers (1999)	Case study	EEE and ink cartridge	Remanufacturer
RemPro matrix	Sundin (2004)	Case study	Unknown	Remanufacturer
REPRO2	Zwolinski et al. (2006); Zwolinski and Brissaud (2008); Gehin et al. (2008)	Analysis/ theoretical	Wide range	Designer (theoretical)
DfRem guidelines	Ijomah et al (2007a,b); Ijomah (2009)	Case study	Various	Remanufacturer
DfRem metrics	Willems and Dewulf (2008)	Unknown	Unknown	Unclear
Hierarchical decision model	Lee et al. (2010)	Unknown	Unknown	Unclear
Energy comparison tool	Sutherland et al. (2008)	Analysis	Automotive	Unclear
Component reliability assessment	Zhang et al. (2010)	Analysis	Automotive	Remanufacturer
Modularisation	Ishii et al. (1994); Kimura et al. (2001)	Theoretical	Unknown	Designer (theoretical)
FMEA	Lam et al. (2000); Sherwood and Shu (2000)	Case study	Automotive	Remanufacturer
Platform design	King and Burgess (2005)	Unknown/ theoretical	Unknown	Unclear
Active disassembly	Chiodo and Ijomah (2009)	Various	EEE	Remanufacturer
Design for environment tools	Pigosso et al. (2009)	Literature review	Unknown	Unclear
QFD	Yuksel (2010)	Interviews	Automotive	Remanufacturer

2.3.3 Agreements and conflicts

There are some points that are commonly raised in the DfRem literature, that appear to have a general consensus around them. Firstly, although the style of proposed methods differs, what is widely agreed amongst key academics in DfRem research is that any approach to improving remanufacturability through design must consider the product and the process concurrently (Bras and McIntosh, 1999, Ijomah et al., 2007a, Sundin, 2004). It is also agreed that economic considerations must be at the forefront of DfRem considerations; there is little sense in improving remanufacturability if it will mean the product is uneconomic to manufacture in the first place (Bras and Hammond, 1996, Linton, 2008). Some researchers have gone as far as to suggest that any DfRem decisions should be made primarily on economic terms (Shu and Flowers, 1999). From a business perspective, key academics cite the combination of remanufacture with product service systems (where the OEM retains ownership of their products) as the ideal model to ensure the efficiency of reverse logistics and encourage more DfRem activity (Sundin et al., 2000, Sundin and Bras, 2005, Sundin and Lindahl, 2008, Sundin et al., 2009). Such a proposal originates from the consensus that OEMs are only motivated to design for remanufacture when they are responsible for the remanufacturing themselves (McIntosh and Bras, 1998).

There are also some instances where conflicts of opinion or conflicts of research findings can be found, most often one researcher or group of researchers speaking out against a common assumption. ‘Design for remanufacture’, as the name would suggest is normally explained in terms of ‘Design for X’, when a particular product quality is focused upon and enhanced (Charter and Gray, 2008, Ijomah et al., 2007a, Sundin, 2004). However, Zwolinski et al. (2006) criticise this definition as it assumes a level of designer knowledge that may not be present. Shu and Flowers (1999) have also identified a problem with remanufacture as a ‘DfX’: some DfRem principles are in contradiction with other ‘Xs’ such as assembly and environment. Similarly Ijomah et al. (2007a) criticised considering remanufacture in isolation when their findings revealed that a more ‘remanufacturable’ product may be inferior in terms of cost effectiveness and environmental performance when compared to a less ‘remanufacturable’ design. Zwolinski et al. (2006) also argue that remanufacturing must be considered as early as possible in the design process, at least during the ‘concept design phase’, as illustrated in Figure 9 (Pahl and Beitz, 1996, Pugh, 1991, Ulrich and Eppinger, 2008). However, many of the tools being offered by academia, particularly those of a quantitative nature, are too complex and technical to be used at a very early stage (Sherwin and Evans, 2000) requiring vast amounts of data that have not yet been defined. By the time these details have been defined, it is often too late to make substantial changes to the design.

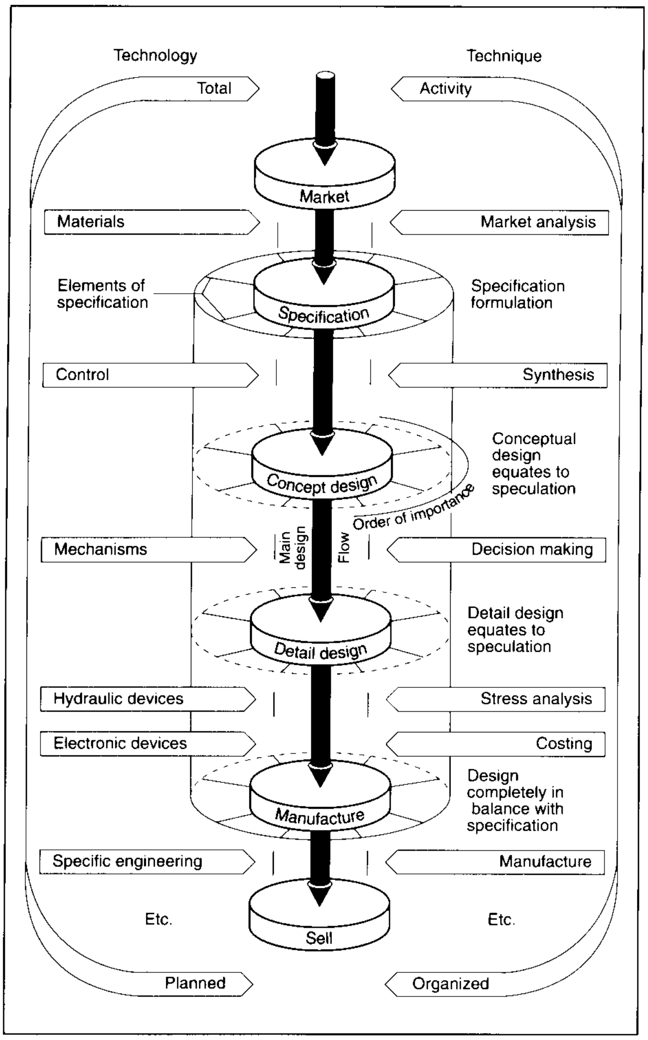


Figure 9: Generic design process, presented in Pugh (1991). The literature states that DfRem must be included at the 'concept design' stage at the latest.

2.4. Integrating DfRem into the Design Process

So far this chapter has discussed DfRem research state-of-the-art in general, which mainly covers DfRem-specific methods and tools. This section will now move on to DfRem integration specifically, which is the subject of this research. Although very little research has been conducted in this area, through a review of the literature three categories of DfRem integration factors were identified: technical, market and operational.

2.4.1 Technical factors affecting DfRem

As previously discussed, design for remanufacture (DfRem) has been a relatively popular subject within the field of remanufacturing research. The majority of work published to date has focused upon the *technical factors* that affect a product's remanufacturability: product features and characteristics that may have a positive or negative effect upon the remanufacturing process, depending upon decisions made during the design stages. Sundin's RemPro Matrix (Figure 6) provides an outline of these technical factors, detailing which factors- such as ease of disassembly or ease of inspection- impact upon which stages in the remanufacturing process. The 'DfRem' guidelines also discussed in section 2.1.1 largely cover technical factors. It is the identification of these technical factors that has contributed to the development of DfRem design methods and tools.

Although technical factors affecting remanufacture have been comprehensively explored in the literature, there remains to be found a suitable approach to ensuring the consideration of these technical factors is better integrated into the design process as a whole, beyond the introduction of methods and tools.

2.4.2 Market DfRem factors

Market factors affecting remanufacture in general have been largely overlooked in the literature to date (Watson, 2008). However, the literature does occasionally refer to the challenges market factors place upon companies involved in the design and sale of remanufactured products. When remanufacture is a successful business venture, there is often strong market demand for remanufactured products. However there is a significant challenge in overcoming the consumer's perception that a remanufactured product is 'second hand' and therefore of lower quality than a newly manufactured equivalent (Charter and Gray, 2008, Debo et al., 2005). This is reflected in the fact that remanufactured products are typically sold at a lower price despite their 'as good as new' quality. Hazen et al. (2012) conducted a survey to determine the relationship between customer's tolerance to ambiguity and the amount they are willing to pay for remanufactured goods, and found that uncertainty of a product's origin and lack of knowledge of the remanufacturing process leads many consumers to demand a lower price. Although lower prices can be advantageous to a company (allowing it to reach a new market segment), these findings show that customer acceptance is clearly a major factor in determining the success of remanufacture.

Technology lifecycles and fashion are also often challenges to DfRem as the drive to design products that spark continuous demand for the ‘latest upgrade’ can at times contradict the requirement to design products that have long-lasting functionality and appeal (Parker, 2007). DfRem could address this issue through ensuring the used product may be upgraded to the latest specification or customer demand (King et al., 2006). However, a barrier to DfRem would be ‘planned obsolescence’, when a company is more interested in sustaining demand for new products than creating long-lasting products.

2.4.3 Operational factors affecting ecodesign integration

The operational factors affecting successful DfRem have been largely unexplored by researchers to date. Hermansson and Sundin (2005) investigated the operational factors that affect the remanufacturing process (including flow of cores, logistics, employees and leadership amongst others), but the research did not extend to OEM design engineering or DfRem specifically.

However, there has been research in the field of ‘design for environment’, also known as ‘ecodesign’, which demonstrates that organisational factors, such as management support or business structure, play a significant role in the integration of ecodesign into a company design process. The results suggest that we could expect some similar factors to be important in the integration of DfRem.

McAloone (2000) conducted a study of designers in the electronics industry to explore how environmental considerations can be integrated into the design process. It was found that the enthusiasm of designers and management was a key factor, and in McAloone’s opinion more important than specific environmental knowledge. Timing of environmental decisions and top management commitment were also found to be important factors.

Johansson (2002) carried out an extensive literature review with the aim of identifying the key success factors for ecodesign implementation (the results are displayed in Table 5). This study involved bringing together the findings from a variety of papers from different sources to create a more definitive list. Johansson found that many of the identified factors were the same as those affecting general success in the product development process, with the exception that ecodesign had differing success factors when considering competencies and motivation, for example specific training in ecodesign and the use of an environmental champion. Boks (2006) attempted to rate the significance of these success factors as well as expand upon them, with a particular focus on the often-neglected ‘socio-psychological’ factors affecting ecodesign integration. Interviews with electronics companies confirmed that not all success factors had equal influence, and suggested less tangible issues such as cooperation and organisational complexities could be more important than technical issues such as tool development.

Like Johansson (2002), Huang and Wu (2010) agree that ‘green product design’ is not very different from regular product design, but adds a new layer of complexity to the design process. Their survey of hi-tech companies in Taiwan revealed corporate commitment, benchmarking and cross-function integration to influence improved integration.

Research by Akermark (2003) focused less upon management systems and process models, and instead focuses upon the perspective of the designer. This study investigated designers’ experiences with regards to ecodesign implementation and environmental regulation compliance, concluding that individual designers play a key role in ecodesign success, yet are often lacking in necessary education and understanding. Opinions expressed regarding designer knowledge of DfRem in Ijomah et al (2007) and Charter and Gray (2008) concur with this finding. Like many other researchers in this field, Akermark stresses the importance of placing ecodesign as early as possible in the product development process, and the importance of providing the right methods and tools for decision-making at this stage. Again similar advice is given in the literature with regards to the use of DfRem methods and tools (Gehin et al., 2008).

Ammenberg and Sundin (2005) take a slightly different approach to ecodesign integration in their investigation of ‘product-oriented environmental management systems’ (POEMS). This work explored the possibilities of integrating ecodesign considerations into a company’s existing EMS, therefore becoming part of the company’s ISO14001 compliance scheme. The authors argue that formalising ecodesign in this manner could reduce the prevalence of non-committal, one-off ecodesign ‘pilot projects’ and instead bring ecodesign to the forefront of every company design project.

More recently, Short et al. (2012) studied ecodesign in Swedish and English manufacturing companies and identified the key external integration drivers to be customer demand and environmental legislation, and the key internal drivers to be personal belief in environmental protection, and demand from management. They also concluded that a low uptake of ecodesign is due to the perception that although ecodesign is a good thing, there are too many unknowns and therefore the risk is too high to fully integrate it into the company design process.

It is interesting to note that the recently published ISO14006:2011 (Environmental management systems- Guidelines for incorporating ecodesign) includes many recommendations that could possibly be relevant to DfRem (Ongondo et al., 2011). These recommendations include:

- Ensuring all those within the organisation involved in product design have knowledge of ecodesign and knowledge of, or access to, ecodesign methodologies and tools.
- Informing all parties involved in the lifecycle of a product (e.g. users, suppliers, distributors, recyclers) about ecodesign requirements or how the environmental impact of the product may be reduced.
- Conducting systematic and periodic design reviews to evaluate the environmental impact of the product throughout its development.

It is important to note that whilst DfRem is often considered to be under the wide umbrella of ‘design for environment’ concerns (due to the potential environmental benefits of remanufacturing), ecodesign research findings are not necessarily interchangeable with DfRem research findings. Firstly, the environmental benefits may vary greatly depending on product type, market sector or company supply chain amongst other factors (Lindahl et al., 2006), and the extent to which remanufacturing benefits the environment is still being debated (Gutowski et al., 2011, Lund, 2011). Furthermore, it has been established that companies are unlikely to decide to remanufacture their products for environmental reasons alone (Ijomah et al., 2007a, Seitz, 2007), meaning the incentives and goals of DfRem are significantly different. Nevertheless, the findings from ecodesign studies provide a good starting point for an investigation of the organisational factors affecting DfRem integration. In particular, the literature study by Johansson (2002) provides a concise yet comprehensive list of top-level operational ‘areas of concern’ affecting ecodesign that provided a basis for interview topics in this research: management, customer relationships, supplier relationships, development process, competence and motivation.

2.4.4 Designer knowledge

There is very little discussion of operational factors to be found in the current DfRem literature. However, both Ijomah et al. (2007a) and Charter and Gray (2008) suggest that a lack of designer knowledge of DfRem principles could be a reason behind the lack of DfRem activity in industry today. What exactly this knowledge would be and how it would be delivered remains unclear.

Nonaka and Takeuchi (1995) discuss the distinction between explicit knowledge (theory) and tacit knowledge (practice), and outline the four modes of knowledge creation in organisations:

- Tacit – tacit (socialisation)
- Tacit – explicit (externalisation)
- Explicit – explicit (combination)
- Explicit – tacit (internalisation)

Whilst some tacit DfRem knowledge has been published in journals (externalisation), and developed into methods and tools (combination), the volume of knowledge is still relatively small, and there is little evidence of internalisation, e.g. the use of methods and tools in industry. This would suggest that much DfRem knowledge creation is at the socialisation stage, to be learned by individuals through shared experiences and social interaction.

Furthermore, Lawson (2004) states that design knowledge specifically is something that cannot be taught, and can only be learned through doing; and that design ability is solution-focused rather than problem-focused, meaning expertise comes from being able to recognise similar problems and solutions. This viewpoint poses challenges to design teams encountering remanufacture and DfRem for the first time.

When discussing the delivery of ecodesign knowledge, Luttropp and Lagerstedt (2005) state that because designers are creative people with tacit knowledge, any knowledge delivered in the form of guidelines must be generic enough to be customisable to specific needs. Boks and Stevels (2007) argue that the use of generic rules or guidelines for delivering knowledge can be counterproductive, and propose that ecodesign knowledge should always be customised to a particular product or project. How the generic DfRem guidelines presented in the literature may be customised to specific needs remains largely unexplored.

Table 5: Ecodesign integration 'success factors', identified by Johansson (2002).

Area of Concern	Success Factors
Management	Commitment and support and provided
	Clear environmental goals are established
	The environmental conditions are addressed as business issues
	Not only the operational dimension of ecodesign should be considered, but also the strategic dimension
	Environmental issues are included when establishing a company's technology strategy
Customer relationships	A strong customer focus is adopted
	Companies train their customers in environmental issues
Supplier relationships	Close supplier relationships are established
Development process	Environmental issue are considered at the very beginning of the product development process
	Environmental issues are integrated into the conventional product development process
	Company-specific environmental design principles, rules and standards are used
	Ecodesign is performed in cross-functional teams
	Ecodesign support tools are used
Competence	Education and training are provided to the product development personnel
	An environmental specialist supports the development activities
	Examples of good design solutions are utilised
Motivation	A new mindset emphasising the importance of the environmental considerations is established
	An environmental champion exists
	Individuals are encouraged to take an active part in the integration of ecodesign.

2.5. Conclusions from the Literature

2.5.1 Summary

Design for remanufacture is an area of remanufacturing research that has received a relatively generous amount of attention over the years; it is widely acknowledged that the design stage of any product's lifespan has a great impact on issues such as cost, manufacturing and end-of-life possibilities. However, remanufacturing research as a whole is limited to a rather small number of papers published over the past three decades, and the importance of expanding DfRem knowledge and working further towards increased DfRem activity in industry should not be overlooked.

It could be argued that the relevance of DfRem research has increased in recent years. The trend in the volume of DfRem research published would certainly seem to suggest this. Yet, in reality, it would seem that an increase in DfRem activity across industry and an increased appreciation for the importance of DfRem is yet to be realised. There could be many products today that are at the end of their lives- or still on the market- that could in theory be good candidates for remanufacture, based on similar examples, yet their designs prevent this from being so. Furthermore, it would seem that many of the products that are remanufacturable today are more so through 'serendipity' rather than conscious design effort (Amezquita et al., 1995). If this problem continues un-investigated, OEMs may not achieve their full potential in terms of remanufacturing process efficiency and the number of products that can be successfully remanufactured.

Considering DfRem integration specifically, the literature review has highlighted a number of technical and market factors that are relevant to integration into the design process. Although no papers were found on operational factors, a review of similar literature from the field of ecodesign has identified a variety of factors which may also be relevant to DfRem, and require further investigation, as summarised in Figure 10.

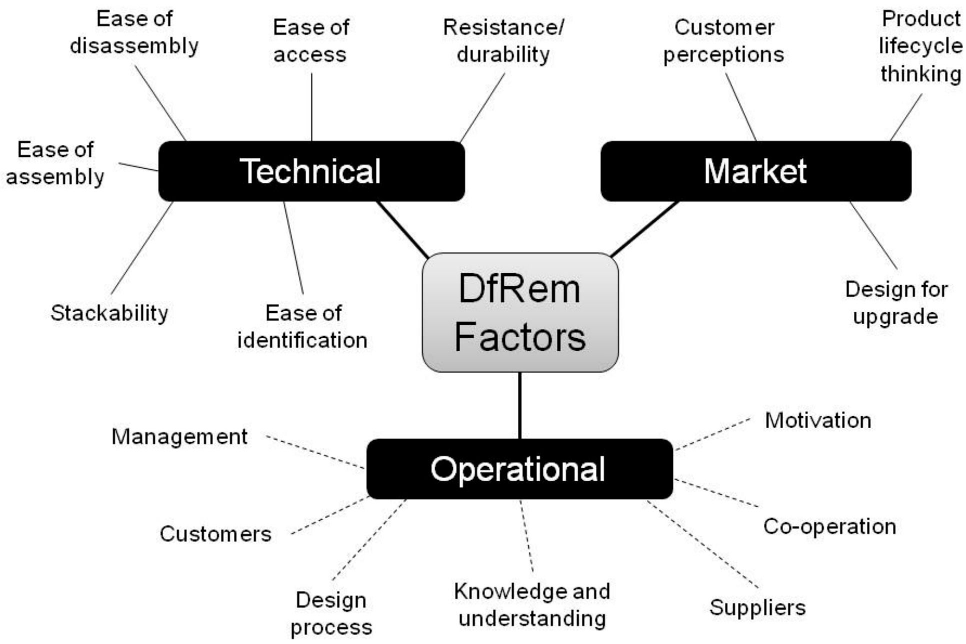


Figure 10: Summary of integration factors, as identified from the literature review.

2.5.2 Implications for PhD research

Reflecting upon the literature review, there were several findings which had a particular influence upon the direction of this research; findings which highlighted gaps in DfRem knowledge to be addressed.

Methodology: Designer/ OEM Inclusion

It is apparent from this literature review that the methodologies followed by previous researchers have primarily involved the study of remanufacturers only. This means that DfRem aids to date, as well as the general understanding of the subject, have been developed solely from the remanufacturers' perspective. Researchers have identified design-related problems faced by the remanufacturer and developed a design method or tool aimed at solving these problems. It has not been considered how these design methods and tools may fit in with an already-complex design process. This means that current DfRem approaches and tools may not fully address the needs of those who actually use them: the designers. A methodology that included the perspective of designers and the OEM in general, could open up several new opportunities for DfRem research, including a study of operational factors.

Therefore it was decided at an early stage that this research should primarily focus upon the OEM/ design engineering perspective.

DfRem Integration

Despite the number of tools and approaches offered by recent research, the literature has indicated that few products are currently remanufactured and even fewer are designed for remanufacture (Charter and Gray, 2008, Giuntini and Gaudette, 2003, Seitz and Wells, 2006, Sundin and Bras, 2005). It would appear that DfRem methods and tools have been developed without questioning why DfRem continues to be an unknown or unpopular activity, despite its increasing visibility in academia. Indeed, it has not been considered whether the provision of appropriate tools and methods is sufficient in securing DfRem's place in the design process. Operational factors that may influence the integration of DfRem have yet to be fully investigated: an identified knowledge gap that steered the direction of this research.

Operational factors: the 'wider picture'

It has been noted that the problem of little DfRem activity has occasionally been accounted for by the claim that designers are lacking in required knowledge and understanding (Charter and Gray, 2008, Ijomah et al., 2007a, Ijomah, 2010). However, these statements are not fully substantiated by empirical evidence, and may be presumptions based solely on the consensus that few products are currently designed for remanufacture. A review of ecodesign literature would strongly suggest that designer knowledge, or 'competence' is not the only factor behind a lack of DfRem, instead there are likely to be many operational factors that have an influence upon integration into a company design process. Whilst these factors provide a useful starting point, the differences between ecodesign and DfRem meant that a research need was identified: an investigation of the operational factors which affect DfRem integration specifically, including but not limited to designer knowledge, to provide a wider picture of how companies may better include remanufacturing considerations in the design process.

2.6. Summary of Chapter 2

Chapter 2 has outlined and discussed the recent literature which presents the state-of-the-art in ‘design for remanufacture’ (DfRem) research. Previous research in this area has primarily revolved around the development of DfRem-specific design methods and tools, and the exploration of the technical design factors which may have an effect on a product’s remanufacturability. In the author’s view, this scope of research does not cover a sufficiently wide range of factors which could influence DfRem’s integration into a company design process; in particular operational factors would appear to have been overlooked to date. Therefore, this chapter has also explored literature published in the field of ecodesign integration, a related subject which provided a starting point for the author’s own investigation into the operational factors influencing DfRem integration. These papers had an influence upon the research design and methodology, as will be discussed in the following chapters.

3. Research Design

This chapter will describe the research design. It will first discuss how and why a multiple case study methodology was chosen and how this directed the research design and data collection plan. The chapter will then go on outline the case study protocol and explain how the research findings were to be validated.

3.1 Characteristics of the Research

3.1.1 Nature of the research

The four research objectives introduced in Chapter 1 can be re-phrased as research *questions*, as the objectives essentially represent the key pieces of knowledge that the researcher wishes to uncover through the course of the research study. Therefore, the overall design of this research was tailored towards answering the following questions:

1. What are the external operational factors that influence the decision to design for remanufacture?
2. What are the internal operational factors that influence DfRem integration into the design process?
3. What are the relationships between these operational factors?
4. How can this knowledge be presented in a way that will enhance its usefulness to an OEM design engineering team?

Based on the characteristics of these questions, it can be said that this research is of a descriptive nature as three of the questions begin with ‘what’ and aim to describe situations, either reality or theoretical (Yin, 2009). It could also be said that this research is explanatory in nature, as it will contribute to explaining the fundamental problem that steered the direction of this research: that very little DfRem is currently carried out in practice. Overall, however, this research is exploratory. The literature review conducted for this study highlighted that there has been very little previous research into this problem, and that operational factors influencing DfRem integration have yet to be fully defined: this research will be investigating these issues in an exploratory manner. Because answers to the research questions cannot be found in the existing literature, the research can also be defined as 'theory-building' as opposed to hypotheses testing.

3.1.2 Philosophical worldview

According to Creswell (2009), the methodology selected by a researcher will be dependent upon their philosophical worldview: their values and beliefs regarding ontology (the nature of reality) and epistemology (the nature of knowledge). Typical worldviews may be:

- Post-positivist, the belief that knowledge is objective and separate from the individual, to be measured scientifically.
- Social constructivist, the belief that knowledge is held in the subjective meaning individuals place on objects, events, processes etc. The understanding of individuals and context are of key importance.
- Advocacy and participatory, in which the researcher has an agenda to help marginalised people, changing lives through more engaging research methods.
- Pragmatism, a rejection of the constraints of post-positivism and constructivism, with more emphasis on solutions to problems than commitment to a particular philosophy.

This research is being carried out with a social constructivist worldview, the belief that knowledge is the understanding of the world held by individuals (Creswell, 2009). Social constructivism is concerned with human interests and aims to increase understanding of a general situation (Easterby-Smith et al., 2008). A key element of this investigation is the study of design engineering, aftermarket and remanufacturing staff's perspectives of DfRem integration, and the reality of DfRem integration and its characteristics are believed to be held within the minds of these individuals- their views and experiences. It is also believed that context, e.g. the working conditions of the designers is very important in understanding why they are or are not currently carrying out DfRem.

3.1.3 Inquiry mode

There are two different routes a researcher can take when deciding upon the inquiry mode of his or her research. Quantitative research is 'a means for testing objective theories by examining the relationship among variables (Creswell, 2009)’. It is highly objective and separated from the researcher. Qualitative, on the other hand is 'a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem (Creswell, 2009)’. It is far more subjective and the researcher must take on a more involved role in data collection.

As this research is mainly concerned with the experiences and perceptions of individuals working within a design engineering OEM (a human-activity system), exploratory in nature and with a social constructivist worldview, a qualitative inquiry mode was selected. First and foremost a qualitative inquiry mode is necessary due to the lack of previous research in this particular problem area. Similar research in related fields has provided priori constructs for the research (ideas of the variables that may be revealed as important), but does not amount to the formation of a reliable hypothesis. Without a hypothesis to test, a quantitative methodology is not a feasible option.

3.2 Selected Methodology

3.2.1 Case study methodology

This research has followed a case study methodology. Meredith (1998) describes a case study in the following way:

‘...*uses multiple methods and tools for data collection from a number of entities by a direct observer(s) in a single, natural setting that considers temporal and contextual aspects of the contemporary phenomenon under study...’*

Meredith (1998) goes on to discuss that case studies are a process oriented methodology. He argues that case study research is most appropriate for building theory in operations management, as, unlike many quantitative or positivist methodologies, case studies are focused upon *understanding* a situation— why certain characteristics occur or do not occur. This understanding is only meaningful within the context of the participants’ assumptions, beliefs and perspectives. This thinking corresponds with the intentions of this research— to understand DfRem integration within the context of immediate stakeholders, rather than objectively explaining why integration does or does not occur.

For this study, the ‘understanding’ is being sought through the sort of case studies that Stake (1995) refers to as ‘instrumental’ case studies: used to achieve something beyond simply understanding the particular case companies involved in the study i.e. the answering of the research questions and building of new theory.

According to Yin (2003) a case study is an appropriate choice when the phenomenon being studied is contemporary in a real-life context, and the boundaries between phenomenon and the context are not clear. Lack of DfRem activity and lack of knowledge about DfRem integration is a contemporary problem that is increasingly being recognised as a threat to the remanufacturing industry.

Gummesson (2000) states that case studies provide holism to a study, as the researcher will be exploring the whole process as opposed to an individual aspect. As this research aims to map the relationships between operational factors influencing DfRem integration into a company design process, with limited inclination of what factors will emerge as significant, a holistic view of OEM design engineering teams and their design process is essential. This means that it was important that the study considered multiple viewpoints within an OEM-remanufacturer organisation, and all aspects of the design process.

Considering the concept of ‘holism’ further, it is beneficial to adopt a systems thinking approach in mapping the relationships between DfRem operational factors. Both product design and remanufacture can be considered ‘human-activity systems’ with a number of interrelated factors influencing DfRem integration (Checkland, 1999). This approach to organisational research is holistic in nature, and an exploratory case study would enable the researcher to consider the design team and the influences surrounding them.

Another advantage of a case study methodology is the potential to use mixed methods should the opportunity arise. Unlike other qualitative methodologies, a case study can utilise quantitative data collection methods as deemed appropriate. Creswell (2009) states that an alternative to a quantitative or qualitative inquiry is a mixed methods approach with a pragmatic worldview, adopting and analysing a wide variety of methods. The limitations of this study, namely time and resources, would make a true mixed-method methodology difficult to execute. Case studies have some of the advantages of mixed methods whilst remaining within a qualitative framework.

Furthermore, an informal survey of the literature revealed that qualitative research, in particular interviews and case studies, are common methodologies in DfRem and ecodesign (a related research subject) integration research. For example, Sundin (2004) used case studies of remanufacturing facilities to investigate product and process design for remanufacture, and Ijomah et al. (2007) used the findings from case studies to develop robust DfRem guidelines. This indicates that case studies are a successful and widely acceptable methodology in this field.

It should be acknowledged that there are significant risks when undertaking case study research, as identified by both the methodology's advocators and critics. A common concern of case studies is researcher bias. Also, according to Eisenhardt (1989) there is a risk that, due to the holistic and open-ended nature of most case studies, the researcher will be overwhelmed with data and the resultant theory will be overly complex. This problem was reduced by limiting the number of case studies and with the formation of constructs prior to entering the field.

Yin (2009) specifies that a case study investigation can be single or multiple, holistic or embedded. This investigation will follow a multiple case study methodology, as this approach enables theory-building from case studies. It was necessary that this research be theory-building in nature because of the considerable lack of previous research conducted on the particular topic of DfRem integration and operational factors. Multiple case studies allows for theories to be built that generalise beyond a single unit of analysis. Furthermore, a multiple case study approach acts as a contribution to the external validity of the study and to allow for theoretical sampling.

3.2.2 Building theory from case study: Eisenhardt

Specifically, it was decided that this research would follow the case study methodology as outlined in Eisenhardt (1989). This particular methodology was chosen as it has been developed for the purposes of theory-building. There is a scarcity of research focused on either DfRem integration or the OEM / design engineering perspective of DfRem, meaning it was not possible to form a reliable hypothesis prior to data collection. Therefore, the aim of this research was inevitably to be the creation of new theory on the operational factors that influence DfRem integration into the design process.

Eisenhardt’s methodology is also appropriate as it has been developed specifically with organisational research in mind, and therefore has an emphasis on producing results that are of benefit to the practitioner. It is of key importance that the deliverables of this research genuinely meet the needs of the OEM, designer, and ultimately the remanufacturer.

The methodology is a multiple case study approach that follows eight well-defined steps, as outlined in Section 3.3 of this chapter. The methodology draws upon both Yin’s (2003) case study methodology and Glaser and Strauss’ (1968) grounded theory methodology. ‘Grounded theory’ is a theory-building methodology which involves the conceptual coding and categorisation of data with continuous comparative analysis. Like grounded theory, Eisenhardt’s methodology should begin with a broad area of interest and no hypothesis to test. However, a key difference between grounded theory and this methodology is that the researcher will instead begin his or her work with the formation of priori constructs (discussed further in Section 3.3.1). The methodology has been criticised for this, as some academics believe that priori constructs will distract the researcher from the context of the case study (Dyer Jr and Wilkins, 1991). However Eisenhardt argues that it is almost impossible to begin research with a ‘blank slate’ and constructs can help shape a stronger research design. At the same time Eisenhardt also stresses the importance of keeping a very open mind and avoiding thinking about specific relationships when in the field. It was decided that this research should begin with priori constructs (as opposed to grounded theory’s ‘blank slate’) to enable a comparison with ecodesign literature to be made (a subject that is often conflated with DfRem).

Another similarity between Eisenhardt’s methodology and grounded theory is the overlap of data collection and analysis. This was considered an advantage when selecting a methodology for this research, as it provides the researcher with the flexibility to adjust and adapt data collection as the theory emerges. If there is very little previous research in this area and the study is being conducted with no definite concepts or theories to test, being able to adjust the research design and take advantage of promising opportunities throughout data collection contributes towards a rounded and reliable study that meets the practitioner’s needs. For example, it was interviewees at the first case study company visited that suggested aftermarket management might be ‘good informants’ for this research, due to their unique insight into both design engineering and remanufacturing.

3.3 Research Design

According to Eisenhardt (1989), there are eight stages to planning and conducting a theory-building case study investigation. This process is highly appropriate for exploratory research due to its flexibility: the data is analysed concurrently with data collection, the process is opportunistic and the research questions are open to alteration as the findings unfold. The process does not demand the formation of a hypothesis or theory to test prior to investigation; it is instead designed to enable the shaping of new theory. Eisenhardt's process is presented in Table 6. The overall research design for this study follows through these steps, as can be seen in Figure 11.

Table 6: Process of Building Theory from Case Study Research (adapted from Eisenhardt, 1989).

Step	Activity
Getting started	Definition of research question(s) Priori specification of constructs (neither theory nor hypotheses)
Selecting cases	Specified population Theoretical sampling
Crafting instruments and protocols	Multiple data collection methods Qualitative and quantitative data combined
Entering the field	Overlap data collection and analysis, including field notes Flexible and opportunistic data collection methods
Analysing data	Within-case analysis Cross case pattern search using divergent techniques
Shaping hypotheses	Iterative tabulation of evidence for each construct Replication logic across samples Search evidence for 'why' behind relationships
Enfolding literature	Comparison with conflicting and similar literature
Reaching closure	Theoretical saturation when possible

3.3.1 Getting started

Whilst this research is exploratory in nature, it was essential that the research aim and objectives were clear from the very beginning. Otherwise, it would have been possible for the researcher to be overwhelmed with data. Hence, this study began with an extensive review of the literature to identify a knowledge gap from which clear research objectives could be developed. As discussed previously, a priori hypothesis is not possible in this study due to the lack of literature in the subject area. However, the study did not begin with a completely clean slate, for example it has been suggested that designers' lack of knowledge is a key hindrance to DfRem activity (Ijomah et al. 2007; Charter and Gray, 2008), and similar studies in the field of DfE have suggested that issues such as management commitment, motivation and customer demand are worth investigating during these case studies. These ideas, or hints, are the constructs from which the research was designed, i.e. they influenced the selection of cases, interview topics, the case study protocol and generally where the focus of the investigation would be. However, it must be noted that some constructs could be considered unimportant as the research evolved, and no construct was guaranteed a place in the final theory. Whilst these constructs were to be kept in mind during case studies, it was important that the researcher should avoid thinking about specific relationships at the early stages of the research (Eisenhardt, 1989).

The priori constructs of this investigation were based upon the common themes present in the literature. As made apparent from the literature review, one construct to be investigated is designers' knowledge of DfRem, as this is a cited cause for lack of DfRem activity (Ijomah et al. 2007; Charter and Gray, 2008). However, in order to view the 'wider picture', constructs were also been taken from similar research in the field of design for environment, or 'ecodesign'. Based on an extensive literature review that builds upon factors influencing successful product development in general, Johansson (2002) provides a list of the key 'areas of concern' when integrating ecodesign into the design process. An adapted version of this list formed the six priori constructs for this investigation, as it was considered to provide a concise yet comprehensive list drawn from a wide-ranging study of the literature (Table 7). Glaser and Strauss (1968), in their guide to grounded theory, recommend that 'borrowing' constructs from existing literature is acceptable in theory-building, providing the researcher continually checks that the constructs still fit, and that emergent concepts are given priority.

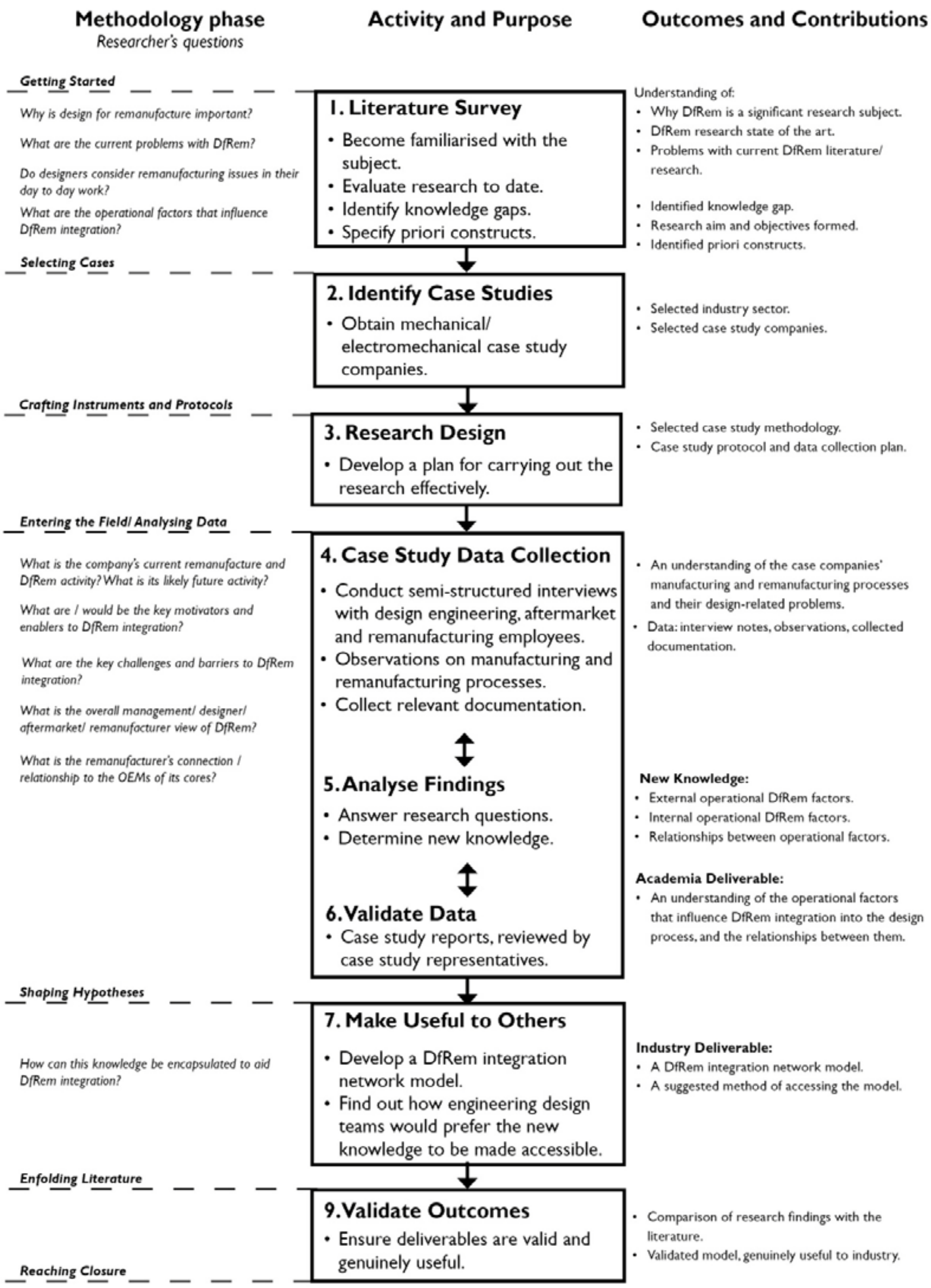


Figure 11: The overall research design, based upon Eisenhardt's 'theory-building from case studies' methodology (1989) and Ijomah (2002).

Table 7: Priori constructs (adapted from Johansson, 2002).

Construct	Example of protocol question
Management	Are management committed to DfRem?
Customers	Is there customer demand for remanufactured products?
Remanufacturer relationships	Do designers receive feedback from the remanufacturer?
Development process	When are end-of-life decisions made?
Competence	What do designers know about DfRem?
Motivation	Do designers feel DfRem is worthwhile and important?

3.3.2 Selecting cases: specified population

Based upon the literature review conducted for this study, a recent survey of UK remanufacturing (Chapman et al., 2009) and general remanufacturing information available online, it would appear that there are two obvious remanufacturing sector groups: mechanical / electromechanical products and (mostly electrical / electronic) consumer goods.

The mechanical / electromechanical categorisation includes products such as engines, gearboxes, machinery and other engineering equipment. They can usually be characterised as predominantly metal, durable and with high value parts. Consumer goods, in this context, would include products such as photocopiers, white goods and office equipment. They can be characterised as having larger proportions of plastic materials and often consist of relatively low-value electronic components. Generally speaking, mechanical / electromechanical products could be considered more naturally 'remanufacturable' because their materials—being durable and of high value— are easier to return to a like-new condition in an economically feasible manner. This claim is reflected in the 2009 survey of remanufacturing value in the UK (Chapman et al., 2009). As can be seen in Figure 12, the remanufacture of mechanical / electromechanical products such as automotive parts is a far more prominent industry sector than that of products such as white goods. However, an informal review of recent design for remanufacture literature shows that much research is focused upon these less remanufacturable (although viewed as 'up and coming' by some) electrical / electronic industry sectors, either in methodology or through case study examples (see Section 2.2.2).

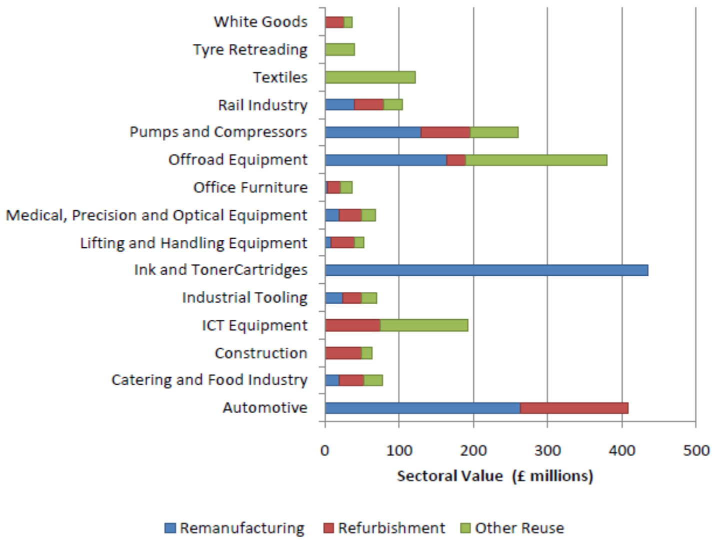


Figure 12: UK remanufacturing value (Chapman et al, 2009).

The choice of industry sector for this research was between the more established mechanical / electromechanical sector and the relatively new and unexplored electrical / electronic consumer goods sector. Of the two identified options, the mechanical / electromechanical sector was chosen (see Figure 13). As this sector is more mature with a higher value in the UK, there are more companies at the present time that could benefit from the findings of this research. Also, if the remanufacture of mechanical products is the most established, the focus of such companies will be turning from remanufacturing set-up to improving remanufacturing efficiency and effectiveness. This is when DfRem will be of greatest concern, because such companies will be interested in fine-tuning their established remanufacturing processes. Finally, conducting case studies in an established industry sector provided a richer resource of data for theory-building research.

As can be seen in Figures 12 and 14, the ink cartridge industry is also a very prominent remanufacturing sector. However, this sector was not considered for inclusion in the research due to the simplicity of the ink cartridge remanufacturing process plus the product's narrow scope for design. Aerospace is also a significant remanufacturing industry sector, yet was not included in the research due to the high complexity of aerospace projects and lack of mass manufacture, making aerospace more difficult to study.

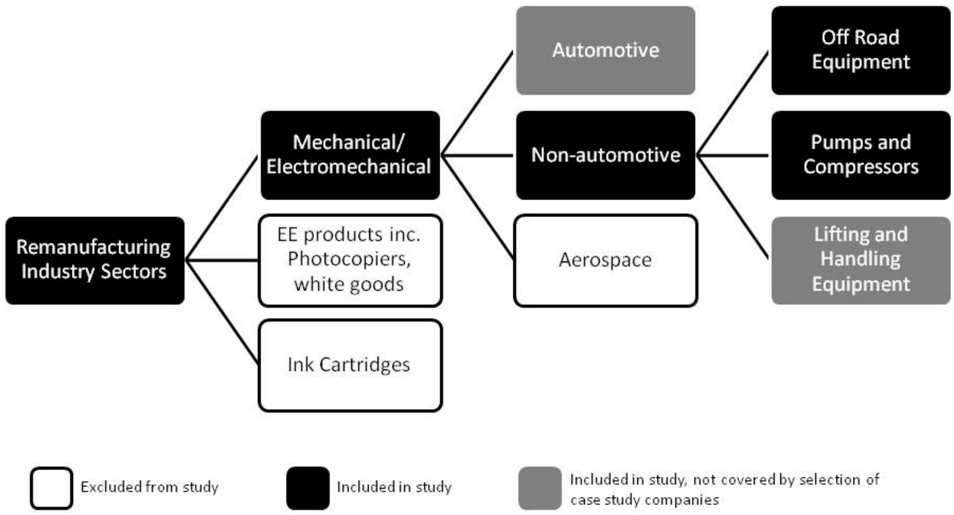


Figure 13: Population selection process for case studies.

This research set out to explore the 'design for remanufacture' of mechanical products such as off-road equipment, pumps and compressors and lifting and handling equipment. Although this population selection was inclusive of automobile products, none of the case companies that agreed to participate in this research fell within that category (although the DfRem integration model was validated by an automotive company). However this was not considered a problem as it was non-automotive sectors which were identified as having the highest value and/or the highest potential for growth in a 2009 UK survey (see Figure 14).

Furthermore, it was also decided that the selected case study companies should be OEM-remanufacturers, as opposed to contract or third-party remanufacturing situations. McIntosh and Bras (1998) state that and OEM-remanufacturer business scenario is necessary for combined product and process design for remanufacture.

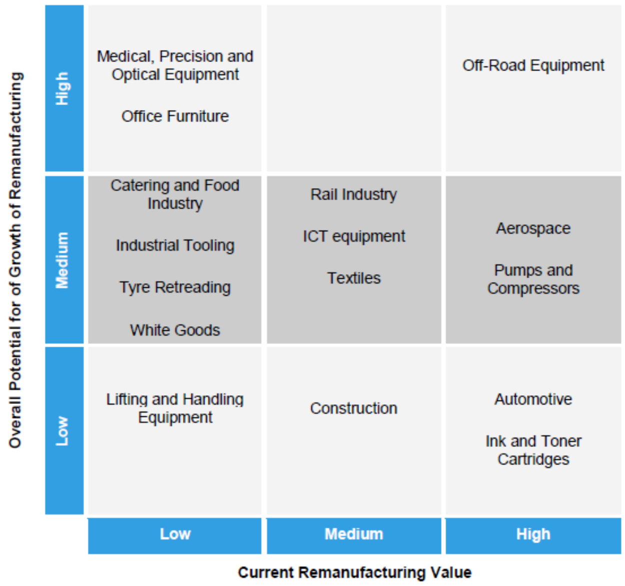


Figure 14: Position of remanufacturing sectors in the UK (Chapman et al., 2009).

3.3.3 Selecting cases: theoretical sampling

In quantitative studies, a statistical procedure is used to select a sample of the chosen population which is considered to represent the population as a whole (Yin, 2009). The studies can be cross-sectional or longitudinal, but the participants are always selected at random. However, in qualitative studies the number of participants is normally much smaller and theoretical (as opposed to random) sampling is adopted. In theoretical sampling, a case is selected to extend emergent theory, fill theoretical categories or provide examples of polar types (Eisenhardt, 1989).

Influenced by similar studies in the field of design for environment, in this research the focus was upon DfRem integration within the context of an organisation, as opposed to simply the personal concerns of individual designers. Data was collected from a variety of sources (including the designers) to provide a holistic view of that organisation's design process and operational DfRem factors which are relevant and within the control of those within the boundaries of the case study, or 'unit of analysis'. The 'unit of analysis' of each case is the design engineering team/ department within an original equipment manufacturer (OEM) from the mechanical / electromechanical sector.

Using theoretical sampling logic, three categories of OEM were identified for multiple cases: 'early stages', 'mid-maturity' and 'advanced maturity' DfRem integration, the logic for which was as follows. Firstly, Lund (1984) identified three different remanufacturing scenarios:

- OEM remanufacturers: the original producer is also responsible for the remanufacture of their used products.
- Contract remanufacturers: the company remanufacture under contract from either the customer or the OEM, who continue to own the product.
- Independent, 3rd party remanufacturers that buy used products to remanufacture and resell. These companies have no connection to the OEM.

It was considered of significant interest and relevance to study OEM-remanufacturers as this is the business scenario for which the OEM could most benefit from DfRem (McIntosh and Bras, 1998). Also, to extend the theory, a second selected case study category was OEMs with potentially remanufacturable products, but with no remanufacturing association to date. Whilst OEMs with current remanufacturing and DfRem activity could provide the richest data (having gone through at least some DfRem integration), it was important that the needs and opinions of those other companies at the very earliest of stages of DfRem integration were included in the emerging theory. After all, it is such companies that could benefit the most from the research outcomes. These categories allowed the research to explore operational factors and remanufacturer-OEM relationships as well as explore the position of designers with presently no obvious incentive to design for remanufacture. It was also desirable to study OEM-remanufacturers at different stages of DfRem integration (or 'maturity') to better understand the various steps and experiences involved in improved integration.

Figure 15 illustrates the three differentiations of case study company investigated in this research (the theoretical sampling). The 'early stages' category represents a case study of a company at the earliest stages of DfRem integration, ideally a company that has not yet begun to consider remanufacturing issues in its design process at all (yet manufactures the kind of products that are typically suited to remanufacture). 'Mid-maturity' represents a case study company that is involved in some remanufacturing activity, yet has not fully integrated DfRem principles into the everyday design process. And finally 'advanced maturity' does not necessarily represent a case company with complete DfRem integration (a subjective concept in any case), instead it represents a company that has already taken more deliberate steps towards better DfRem integration.

Yin (2009) also promotes literal replication when selecting case studies- conducting similar cases with the hope of finding similar results, thus improving the external validity of the investigation. Additionally, Eisenhardt (1989) believes that between 4 and 10 cases are preferable for a successful theory-building case study investigation. Therefore, in an ideal situation, each of the theoretical sampling categories would be replicated.

Although the case study design has been described as 'multiple holistic' (multiple case studies with one unit of analysis), there is also a resemblance to embedded case studies, where multiple units of analysis are investigated within a single case (Yin, 2009). This similarity, as illustrated in Figure 15, is due to the ambition that this study will explore the perspectives of both the designer and the remanufacturer. Therefore, for cases with remanufacturing associations, the remanufacturing operation was also studied, increasing understanding of design-related remanufacturing problems and the relationship between remanufacturers and OEM design engineering teams. This inclusion provides a more holistic view of DfRem integration and improves the construct validity of the research as a whole (data triangulation). However, the focus of analysis will remain upon the design engineering teams.

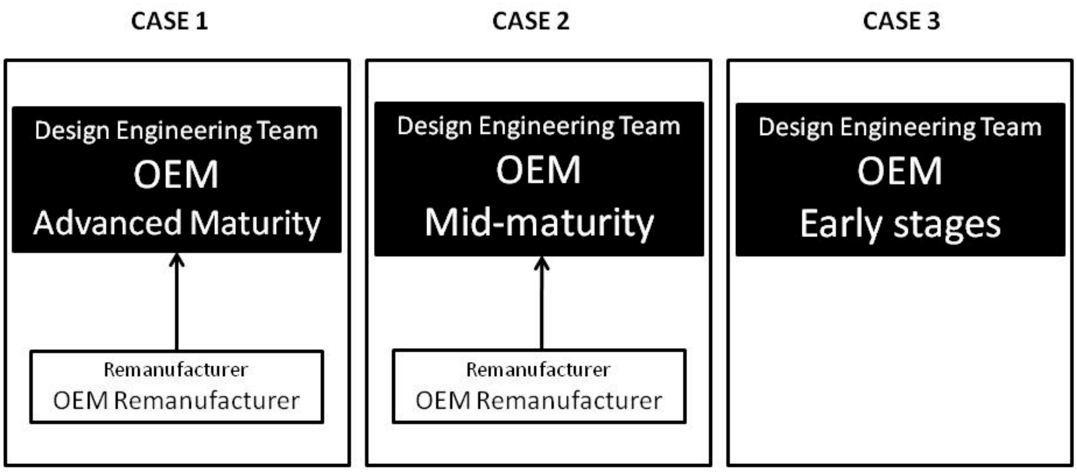


Figure 15: Theoretical sampling categories

Explaining the unit of analysis in more depth, an OEM engineering design team would be considered the 'human-activity system' under investigation in this research. The DfRem integration network model was developed from this perspective, considering those operational factors that directly influence the engineering design team and are within their control (internal factors). DfRem integration was studied from an operational perspective, and therefore the OEM organisation (including remanufacturing operations) and external operational factors are classed as the ‘wider system’ in which the engineering design teams were investigated. The individuals and groups that provide data for the research (e.g. interviewees) are the sub-systems of the investigation. This hierarchy of systems under investigation is illustrated in Figure 16. Note that the sub-systems outlined sample interviewees from four different perspectives: from within design engineering, and immediate stakeholders in DfRem integration. These four groups of interviewees, which are discussed in more detail in Section 3.5.2, were included in the study as they were considered to be potential ‘good informants’, who would have different knowledge and experiences to share that would be of value to the research (Morse, 1998 in (Flick, 2009)).

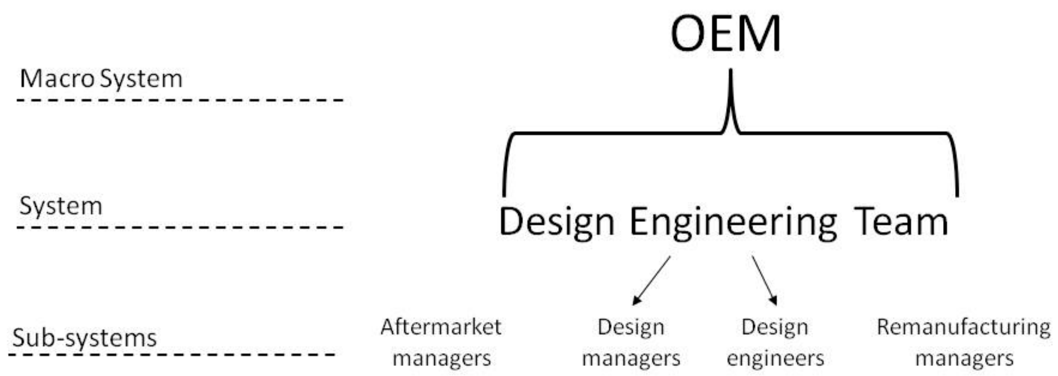


Figure 16: The systems hierarchy, with the design engineering team as unit of analysis.

3.3.4 Crafting instruments and protocols

Within a multiple case study approach, the researcher can adopt one or more different methods of data collection, tailored towards obtaining the desired information. Eisenhardt (1989) states that interviews, observations and documentation sources are the most commonly adopted case study data collection methods, and a combination of two or more is important in ensuring triangulation. Drawing upon different sources of information (interviews, observations and documentation; managers, designers and remanufacturers) leads to a stronger theory and constructs. This also allows for flexibility in the way data is collected; the key aim is to gain as much understanding about each case as possible, granted that any alterations in data collection are systematic and controlled (Eisenhardt, 1989).

At this stage in the research process a case study protocol was developed. Having a protocol increases the reliability of a study as it keeps the researcher focused on the topic of study and forces them to anticipate potential problems (Yin, 2009). Following a protocol helps ensure that each case study in a multiple case study approach is carried out in a similar manner, again improving reliability and ensuring data collected is comparable. The protocol for this research was developed in accordance with the framework as outlined in Yin (2009). The protocols were structured as follows:

Overview of the case study project: A brief background to the research, the research aim and objectives, and the purpose of the particular case visit (OEM or remanufacturer).

Field procedure: The procedure for gaining access to case companies, a summary of the data collection methods to be used and a list of required resources for the case study visit.

Case study questions: The questions to keep in mind during data collection. There are four different levels of questions: those directed at interviewees, those asked of the particular case study, questions relating to data analysis and questions asked of the entire study. The case study questions are discussed in more detail in Section 3.5.3.

Structure of the case study report: A guide to the writing of the case study report, or within-case analysis. The case study report is discussed in Section 3.5.6.

3.3.5 Entering the field

According to Yin (2009) construct validity is achieved in case study research through 'triangulation', or multiple sources of evidence. When entering the field there were three key methods of data collection:

1. Observation of the manufacturing and remanufacturing process. This method was of most advantage during remanufacturing visits, allowing the researcher to follow the remanufacturing process and understand the context of any design issues that may

arise. Manufacturing observations were also beneficial for prompting discussions on the remanufacturability of the products being manufactured.

2. Interviews with members of engineering management, aftermarket management and designers (OEM), as well as remanufacturing management (remanufacturer). It was important that these interviews were semi-structured to ensure objectives and priori constructs were covered, but at the same time ensure the conversation was not limited to these constructs (allowing for new themes and theory to emerge).

3. Official documentation such as environmental policy, design checklists, design and remanufacturing specifications, company websites and remanufacturing promotional material. The advantage of this method is that documentation is stable and exact, as well as unobtrusive (employees' time is precious). However there is a risk of bias through selectivity and confidentiality issues can make access difficult (Yin, 2003).

Of these three methods, it was expected that interviews would prove to be the richest source of information, because DfRem is a human-activity system and the research was therefore focused upon the experiences and perceptions of the *people* involved in DfRem integration.

3.3.6 Analysing data

Eisenhardt's process involves an overlap of data collection and data analysis; it is recommended that the researcher takes extensive field notes during the case study and carries out within-case analysis for each case as it is investigated. This speeds up the analysis process and allows for adjustment to the data collection as the theory begins to emerge. These detailed write-ups of individual cases were then followed by cross-case pattern searching, for which within-case findings are compared and contrasted with one another. Cross-case analysis reduces premature conclusions and researcher bias when theory-building, and can result in more novel findings due to a more sophisticated understanding of the findings (Eisenhardt, 1989).

Within-case analysis

Within-case analysis, the first stage of analysis for every case study, is presented in the form of a case study report. This is a relatively summarised document of the key findings from that particular case study. It is presented to key informant(s) from the case study company (e.g. engineering manager) not only for their own interest but also for purposes of construct validity: the company can then verify that all representations are accurate and fair. Each case study report followed the same structure as follows:

1. The company's current remanufacturing activity.
2. The company's current DfRem activity.
3. The key DfRem motivators and enablers.
4. The DfRem barriers and challenges.
5. The overall management view of DfRem.

It must be made clear that the case study reports represent merely reiterations of the data collected during the case study. This information is taken directly from what has been said, read and seen during interviews and observations, and must be verified by those who are being represented in the report.

Cross-case analysis

'Cross-case analysis' is when the researcher begins to compare data from one case with another, in order to identify key differences and similarities that will enable patterns, trends and relationships to emerge. Miles and Huberman (1994) suggest creating matrices of categories, and providing evidence for each entry to a matrix. Influenced by this text, it was decided that several matrices would be used to analyse across the research cases:

- A matrix that compares the external operational factors (research objective 1) for each case study company. This exercise revealed which external factors were common across the cases and which had the strongest evidence supporting them.
- A matrix that compares the internal operational factors that were found to influence DfRem integration (research objective 2) for each case study company. This exercise revealed the factors that are most common across the cases and which had the strongest evidence supporting them. This matrix also provided some indication of what DfRem integration 'maturity' could mean.
- A 'role-ordered matrix' that compares the findings from each interviewee group across the case studies (engineering managers, design engineers, aftermarket

managers and remanufacturing managers). This exercise provided richer insight into the commonalities and patterns across the case study companies, as well as an understanding of which factors were relevant and important to which DfRem stakeholders.

- A matrix that identifies the relationships between operational factors and the evidence to support them (research objective 3), enabling the creation of a systems diagram of DfRem integration (research objective 4).

3.3.7 Shaping hypotheses

Case study analysis should identify the emergent constructs (internal and external factors) and relationships which influence DfRem integration into the design process, as evident from the case study data. The next step in Eisenhardt's methodology, 'shaping hypotheses', is about refining and validating these constructs and relationships into the final outcomes of the research. It is a continuation of the process of iteration which began with the evidence matrices outlined in the previous section: comparing the evidence from each case study to determine whether a construct or relationship can be confirmed, disconfirmed, requires revision or must be thrown out for lack of strong evidence.

This process involved taking each factor and relationship in turn and again attempting to provide evidence from each case study for confirmation. Because this research investigated three case study companies at different stages of DfRem integration, it was to be expected that replication across the three cases would not always be the case: some factors and relationships would be present in companies with better integrated DfRem, which were not currently relevant to a company that did not design for remanufacture. Eisenhardt states that in such instances the case study data must be used to explain why the construct is not present in a particular case study, therefore extending the theory. This is also the case for constructs and relationships present in all three case study companies, as it is important when shaping hypotheses to be able to demonstrate that a relationship is not simply a coincidence, and that it is not simply the case of a third construct influencing the two. Because theory-building research is more qualitative than theory-testing, with no statistical data to refer to, this hypothesis shaping process is likely to be more subjective, and more judgemental on the researcher's part.

It was also at this stage that the integration network model would be developed, based on the emerging theory. The intention at this stage was to communicate the new knowledge generated through the research in an effective and accessible manner. The decision to present the emerging theory as a network model was influenced by the concept of soft systems thinking and Design Research Methodology (DRM). ‘Soft systems thinking’ is concerned with looking at a problem situation as whole; as a range of linked or interdependent factors (Checkland, 1999). These systems are typically graphically presented as a network model showing the relationships between factors within a specified system. DRM, developed by Blessing and Chakrabarti (1999), is a methodology geared specifically towards understanding the phenomenon of design and all its facets, including the organisation. This methodology also involves the identification of a ‘network of influencing factors’ and subsequent model development, which should either describe an existing design situation, or present a desired design situation. In both cases, the models are not intended to represent reality, but rather some aspects of that reality in the context of stakeholder’s perspectives.

3.3.8 Enfolding literature

The next step in Eisendhardt’s methodology involves comparing the final research outcomes with the existing literature in the field, literature that was used to form the priori constructs for theory-building. Comparing the findings with both conflicting and similar literature in both the field of DfRem and the relevant ecodesign papers builds internal validity into the research and enhances the generalizability of the research.

It was anticipated that some operational factors identified through the research would match the priori constructs, some would contradict them, and other, new factors would emerge from the case study research. It is therefore of value to the research to look back to the original priori constructs for comparison, and where anomalies are found, be able to explain ‘why’ these differences occur, therefore strengthening the overall theory. According to Eisenhardt, comparison with similar literature is also important because ‘it ties together similarities in phenomena not normally associated with one another’. This is particularly significant in this research as the literature comparison will help contribute to determining how similar or different DfRem integration is to ecodesign integration.

3.3.9 Reaching closure

According to Eisenhardt, there are two important factors to consider when deciding when to end the research. Firstly when ‘theoretical saturation’ has been reached, meaning any additional case studies would provide minimal new insight in comparison to the time and resources required to carry out that case study. The second indication of reaching closure is knowing when to stop iterating between theory and data, i.e. creating new tables and matrices, refining constructs and models. Eisenhardt recommends this process should stop when improvement to the theory is minimal.

3.4 Validation

3.4.1 Research findings validity

According to Yin (2009), the quality of an exploratory case study investigation may be tested under three categories:

- Construct validity, ‘identifying correct operational measures for the concepts being studied’. This is achieved by using multiple sources of evidence (such as interviews and observations, design engineering, aftermarket and remanufacturers), establishing a chain of evidence, and having key informants (e.g. design managers) review a draft of the case study report.

- External validity, ‘defining the domain to which the study can be generalised’, achieved through the use of replication logic when selecting cases.

- Reliability, being able to demonstrate that the study could be repeated (by another researcher) and yield the same results. This is achieved with the use of the case study protocol and case study database (a body of evidence separate from the final report).

According to Thomas and Tymon (1982), if research is to be deemed genuinely relevant and useful to industry, the results much meet five practitioner needs:

- Descriptive relevance: accurate results.
- Goal relevance: identified factors correspond with those the practitioner wishes to influence.
- Operational validity: ensure practitioners have ability to control identified factors.
- Non-obviousness: theory exceeds common sense of the practitioner.

- Timeliness: the theory is available to practitioners at a time when it is needed.

These criteria were considered during the validation of the final research outcomes, which is discussed in the next section.

3.4.2 Model validity

Once it could be confirmed that the research data was accurate and reliable via the case study reports, the new knowledge was then developed to create a DfRem integration network model. As this model took the research findings a step further, it was important to ensure that this final outcome of the research was validated sufficiently. Checkland (1995) states that absolute validation of a soft-systems model is unnecessary because these models are not designed to represent 'reality'. Instead they represent a stakeholder's viewpoint. However, others such as Coyle and Exelby (2000) state that whilst there is no such thing as absolute validity for soft systems models, validation can indicate the degree of confidence in the usefulness of the model. In more quantitative model development, validation is intended to ensure sufficiency, clarity and appropriateness (Barlas, 1996).

The model validation process for this research incorporated elements of all these viewpoints, and a review method was adopted. Validation was conducted in two phases: a review panel of employees from a case study company and a review panel of employees from a non-case study company from the mechanical / electromechanical sector (in order to provide a fresh perspective on the research and extend the generalisation of the research). For each review panel the same protocol was adopted: attendees had knowledge and experience of engineering management and / or remanufacturing, were presented the research findings in the same format and requested to complete two questionnaires individually in addition to group discussion. The validation panels sought three key elements of feedback:

- Model content: is the information presented in the model accurate and representative? Are there any omissions?
- Model presentation: is the information provided clearly communicated? Is the layout of information easy to understand?
- Model accessibility: in what format should the model be accessed? Who would want access to this information?

This feedback, combined with feedback from relevant academic experts, was incorporated into the final version of the model, which is presented in this thesis.

3.5 Case Study Protocol

3.5.1 Gaining access

Potential case study companies were identified using both lists of university contacts and the internet (search engine results) to identify companies which met the appropriate criteria:

- Companies that manufacture mechanical / electromechanical products (the specified population, as discussed in Section 3.3.2).
- Companies that carry out design engineering activities in the UK (for time and resource reasons).
- Companies that fall under one of the following categories (theoretical sampling):
    - Early stages of DfRem integration (no current remanufacturing activity).
    - Mid-maturity of DfRem integration (remanufacturing but no or little DfRem).
    - Advanced maturity of DfRem integration (remanufacturing, with products designed for remanufacture).

Once identified, potential case study companies were contacted by telephone, speaking where possible to a member of design engineering management. Following a brief discussion about the research and its possible relevance to the company, interested managers were then emailed a document that would provide them with more information about the research and what participating in the case study would involve. If the company then chose to participate, follow-up phone calls and emails were used to make plans for the first case study visit.

3.5.2 Case study procedure

To ensure construct validity, or ‘triangulation’ of evidence, multiple sources of data were utilised during each case study. Semi-structured interviews were the primary source of data for this study, as many of the case study questions were connected to individual’s thoughts and opinions, as well as their experiences in their specific roles within the company. Within this data source, construct validity was strengthened through the interviewing of staff from several different business areas (or perspectives) within each case study company:

- Design engineers (often referred to in this thesis simply as ‘designers’): members of the design engineering team involved in new product development. These were the individuals who were either currently doing DfRem, or could be expected to do so in the future.
- Engineering management: members of the design engineering team who oversee new product development and are / would be responsible for making the most major decisions regarding DfRem integration. Compared to designers, engineering management were also most likely to have a greater insight into how the company operated as a whole and the external operational factors influencing DfRem.
- Aftermarket management: managers responsible for the sale of spare parts and the coordination of servicing and maintenance of company products throughout their lifecycles. These interviewees were often able to provide a unique perspective on DfRem integration as aftermarket managers are a part of the OEM yet have an insight into end-of-life processing.
- Remanufacturing management (where applicable): managers overseeing the company’s remanufacturing processes. Although often unable to comment on DfRem integration per se, these interviewees were able to provide another perspective on the remanufacturability of the case company’s products, and also discuss their perspective on the relationship between OEM and remanufacturer.

Where possible, multiple employees were interviewed from each business area. A summary of interviewees from each case study company can be found in Table 8.

The second most significant source of data was personal guided tours (‘observation’) — of both the company’s manufacturing and remanufacturing facilities. These tours were opportunities to observe the remanufacturability of the company’s products first hand, with an engineering or remanufacturing manager available to answer questions regarding the technical factors affecting DfRem integration. These discussions of technical factors would often lead into discussions of operational factors as well.

Lastly, some case study data was also collected from documentation such as official company brochures, websites, articles, design checklists, company and industry standards and design specifications. Documentation provided verification of some operational factors discussed by interviewees, and also provided a greater insight into how these factors influence DfRem integration.

3.5.3 Case study protocol questions

Prior to conducting the first case study visits, a case study protocol document was produced. This protocol provided guidance before, during and after the visits, ensuring the research remained directed towards the overall research objectives.

For the advanced and mid-maturity case studies, it was necessary to adapt some questions to be directed towards the companies' remanufacturing facilities. Remanufacturing management had a rather different insight and perspective of DfRem, and therefore some protocol questions had to be adapted accordingly.

The structure of the protocol questions was adapted from Yin (2009).

Level 1 protocol questions

Level 1 protocol questions are those asked of individual interviewees. Because interviewees participating in the research came from a variety of backgrounds and roles (and because the research is exploratory and theory-building), interviews were semi-structured and therefore did not involve a definitive list of questions. Instead, the protocol provided suggestions of the *kind* of questions that may arise during interview conversations:

OEM Questions

- What end-of-life considerations are you currently involved in?
- What happens to your products when they reach end of life?
- Where do you see end-of-life processing being in 5, 10, 15 years time?
- What would influence your decision to include DfRem in the design spec?
- What communication/ feedback do you have with your remanufacturer?
- How is environmental legislation affecting the company now, and in the future?
- Do you feel you could carry out DfRem if it were added to the design spec?

Remanufacturer Questions

- What design information do you have access to?
- What are the most complicated aspects of your remanufacturing process?
- For what reasons would you contact the OEM?

- If you had a problem with a particular design, what would you do?
- Where do you see end-of-life processing being in 5, 10, 15 years time?
- How is environmental legislation affecting the company now, and in the future?

Level 2 protocol questions

Being semi-structured, interview discussions varied depending upon interviewees particular roles within the case study company. However, a set of interview topics or themes directed all conversations. These level 2 ‘questions’ outline these topics:

OEM Questions

- What is the company’s remanufacture and DfRem activity?
- What is likely to be their future activity?
- What is the overall management/ designer/aftermarket view of DfRem?
- What are the key barriers/ problems associated with integrating DfRem?
- What would be the key motivators to integrate DfRem?

Remanufacturer Questions

- What is the remanufacturer’s connection/ relationship to the OEMs of their cores?
- What design related problems and barriers does the remanufacturer currently face?
- What other problems and challenges do they face?
- What communication is there between remanufacturer and OEM?

These topics enabled the interview data to create an overall picture of DfRem integration within these companies as well as provide a deeper insight into the interviewees own knowledge, understanding and attitudes towards the subject. For example, different employees within the same company could provide quite different views of the future of remanufacturing and DfRem, and different employees would be concerned with different problems and barriers to integration, depending upon what most affected their own roles within the company. These topics also allowed the conversations to be steered towards the ‘priori construct’ factors, such as competence, motivation, management and the design process. For example, asking designers about the company’s current remanufacturing and DfRem activity could reveal to what extent they were aware of the remanufacturing process and DfRem principles (competence). Furthermore, the interview topics helped alleviate researcher bias and improve reliability by enabling the framing of questions in different ways (Yin, 2009). For example, asking questions about the company’s future DfRem activity, and asking questions about DfRem integration motivators could return similar answers, reaffirming these findings.

Level 3 protocol questions

These questions relate to analysis of the data; in particular ‘pattern finding’. If level 2 questions are ‘within-case analysis’ then level 3 are ‘cross-case analysis’ (Eisenhardt, 1989).

- What are the similarities between cases?
- What are the differences?

3.5.4 Interview protocol

Interviews were semi-structured, meaning that the content of each discussion would vary from person to person, company to company. The ethnographic style of questioning adopted (Spradley, 1979) meant that questions were largely open-ended and required long, descriptive answers from interviewees, answers which were more variable than a straightforward structured interview would produce. This was appropriate for exploratory research that is interested in interpreting the understanding of a human-activity system.

However, it was important that consistency and professionalism was present across all interviews conducted for the research. Interviews were kept consistent through the use of the level 2 case study questions, which were referred to during interviews (but not presented to the interviewees, to ensure a natural flow of conversation). It was also important that all interviewees understood the purpose of the interview.

According to Richards (2009), it is important to consider how participants will perceive both the researcher and the study. Spradley (1979) also suggests it can be beneficial to express ‘cultural ignorance’ during interviews to encourage interviewees to share information. The majority of interviewees in this study were not accustomed to thinking, or talking, about DfRem integration in such detail. For many this was a rather abstract and unfamiliar concept that was difficult to visualize. It was therefore important that the researcher was not perceived to be an ‘expert’, but rather a student who is studying DfRem practices and keen to learn from practitioners. Therefore ‘cultural ignorance’ questions were an effective method of putting interviewees at ease and encouraging them to share more information.

3.5.5 Case study companies overview

Three companies agreed to participate in the case study research, each of which fell under different levels of DfRem integration maturity defined for the purposes of theoretical sampling:

- Advanced stages of DfRem integration: Company A
- Mid-maturity DfRem integration: Company B
- Early stages of DfRem integration: Company C

Company A

Established in the UK in the 1930s, today Company A is a subsidiary of a global manufacturer of off-road equipment. The company has a heritage of producing diesel engines for agriculture, construction and power generation amongst other purposes. As well as a headquarters, Company A has several UK manufacturing and remanufacturing locations. Case study research was carried out at three of Company A's facilities. Location 1 is a facility where diesel engines are designed and manufactured for the power-generation market. Location 2 was a UK facility (now relocated) for the parent company's remanufacturing operations, and was responsible for the remanufacture of Company A's engines as well as contract remanufacturing for other OEMs. Location 3 is the company's UK headquarters, and the location of the design and manufacture of smaller diesel engines for the off-road equipment market, most often for use in parent company vehicles.

The Company A case study took place across three separate visits, to three of the company's UK facilities. Firstly, Location 1 was visited in February 2011, followed by a visit to Location 2 in March 2011. It was then decided, in August 2011, that a visit to the company headquarters was necessary (Location 3), to gain better insight into the relationship between the OEM and remanufacturer. The details of the data collection carried out during these three visits (and follow-up phone calls and emails) are outlined in Table 8.

Company B

Company B is a pump manufacturer with a long history, dating back as far as 1871. The company currently operates under 8 different business units: upstream oil; downstream oil;

nuclear power; conventional power; water and industrial; minerals and mining; offshore and marine; and aftermarket. The case study was carried out at the company's UK headquarters, which specialises in upstream oil and nuclear power engineering. The facility also accommodates one of the company's major service bays, where remanufacturing takes place amongst other service processes.

Company B has grown over the years through many acquisitions and mergers, and the most recent business change came during the course of this case study- in 2011 the company was sold to a US brand for £750million. However, the UK management team behind Company B has remained unchanged following this acquisition. The parent company has annual revenues of $5.5billion and employs more than 15000 people in 35 countries.

Company B's headquarters, which were visited for this case study, remain the largest manufacturing facility in the company, with 981 staff. These facilities include a service bay, to which customers can return their pumps for remanufacturing. When Company B took part in a merger in 2008, it lost access to part of the original aftermarket service for sold equipment. Therefore the Company B aftermarket department is young in comparison to the rest of the company's long history.

Tours and interviews were conducted over several short visits between February 2011 and January 2012. The details of these visits are outlined in Table 8.

Company C

Company C is a US-founded manufacturer that is in the business of making acquisitions of companies producing off-road equipment for construction, quarrying, infrastructure and other industries. It is now the world's third largest manufacturer of construction equipment. In 2011 the company had revenue of $6.5 billion and employed more than 22600 people worldwide.

Company C has several UK locations. The location where the case study data was gathered is responsible for the design and manufacture of rigid and articulated dumper trucks, primarily for use in mining and quarries. Its main customers are distributors who would then sell on the trucks to the end user. The trucks could largely be described as mechanical products, although the cab interiors of articulated trucks in particular include increasingly sophisticated electronic elements.

Case study data from Company C was collected primarily from two visits to manufacturing facilities in May and November 2011, as well as an earlier conference call with design and aftermarket management. Details of data collection are outlined in Table 8.

Table 8: Overview of data collected from the case study companies. As can be seen, the more advanced in DfRem integration the company, the more sources of useful data were available for the research.

Location	Date	Data Collection method	Number
Company A			
Location 1: UK manufacturing	Feb 2011	Interview: design management	4
		Interview: design engineer	2
		Interview: aftermarket management	1
		Observation: manufacturing tour	1
		Documentation	3
Location 2: UK remanufacturing	Mar 2011	Interview: remanufacturing management	3
(parent company)		Observation: remanufacturing tour	1
Location 3: UK manufacturing	Aug 2011	Interview: design management	2
(headquarters)		Interview: design engineer	2
		Interview: aftermarket management	1
		Observation: manufacturing tour	1
Company B			
UK manufacturing	Feb-Jul 2011	Interview: design management	2
(headquarters)		Interview: design engineer	2
		Interview: aftermarket management	2
		Observation: manufacturing tour	1
		Documentation	1
UK service bay	Jan 2012	Interview: remanufacturing management	1
		Observation: remanufacturing tour	2
Company C			
UK manufacturing	May-Nov 2011	Interview: design management	1
		Interview: design engineer	2
		Interview: aftermarket management	2
		Observation: manufacturing/ service tour	2

3.5.6 Reliability: case study reports

Although extensive notes were taken during each case study visit and interview, it is entirely possible that misinterpretation, bias, and even simple human error can result in case study 'findings' which are inaccurate, incomplete or misleading. Therefore, it was important to ensure that data collected from each case study was as accurate and representative, to help ensure that the case study findings and conclusions were of as high a quality as possible. According to Yin (2009), 'reliability' in case study validation is about ensuring that if another researcher were to conduct the same case studies, they would arrive at the same findings and conclusions. Although for this study it was not feasible to carry out this reliability test, measures were taken to ensure that in theory it would be possible. The review and correction process that the case study reports underwent enhanced the construct validity of the research (Yin, 2009).

To improve the reliability of the within-case study findings from each company, case study reports were written once all data collection activities had been completed. They could then be reviewed and verified / amended by key correspondents from the case study company (engineering and aftermarket managers). These reports were brief and concise to ensure the correspondent would be willing to read them, yet detailed enough to include a reiteration of all essential facts and opinions recorded during data collection. Correspondents were then given the opportunity to state whether they agreed with the case study report, and where amendments or clarifications should be made. Whilst it was acceptable for case study correspondents to disagree with the researcher's conclusions and interpretations, there should be no disagreement over factual information regarding the case study company (Yin, 2009).

For the three case study companies involved in this research, the 'key correspondents' who were asked to review their respective case study reports were one design engineering manager and one aftermarket manager. Managers were selected for this task because they were most likely to have the most insight and knowledge of the issues being discussed in the report, and representatives from both design and aftermarket were selected to ensure all facts were covered and a balanced view was gained.

The case study reports outlined facts gathered under five topics:

- The company's current remanufacturing activity.
- The company's current DfRem activity.
- The company's key DfRem motivators and enablers.

- The company's key DfRem barriers and challenges.
- The overall management view of DfRem (attitudes, opinions, perceptions etc).

As Yin (2009) suggests, the case report review process provided an excellent opportunity to produce further case study evidence, as correspondents were able to add new information they had previously forgotten to mention, or expand upon information or add new opinions or insight to information given by other participants in the case study research. This was particularly significant for Company B. Because the case study report was reviewed by both engineering and aftermarket management, the review process revealed several disagreements between the two parties over the degree to which serviceability is considered during the Company B design process. Although this issue made determining the objective facts from personal perceptions difficult, it was also of value to be made aware of this conflict.

After the initial case study report review, reports were amended and updated as necessary and returned to correspondents, until all correspondents were satisfied that the contents of the reports were accurate, comprehensive and representative. The final drafts of the case study reports can be found in Appendix 1.

3.6 Chapter Summary

Chapter 3 has explained how the selected methodology was arrived at, from the understanding that the research must be qualitative in nature to the decision to conduct multiple case studies. The overall research design is outlined, from selected case study population and priori research constructs to shaping hypotheses and enfolding literature. The chapter has also explained how the research findings and resultant model would be validated.

Chapter 3 has also outlined the case study design, or 'protocol'. This protocol, which included plans for data collection and different levels of case study questions, ensured that the author entered the field as prepared as possible for gathering rich and useful data for analysis which covered all aspects of the research aim and objectives. Three suitable case study companies were identified and each case study followed the same protocol. The resultant findings from the case studies will be discussed in the following chapters.

Chapter 4: The Operational Factors That Influence DfRem Integration

This chapter begins the presentation of the research findings: the external and internal operational factors which were found to influence DfRem integration into the design process. The chapter will outline each identified factor in detail, and discuss how within-case and cross-case analysis enabled the research to lead to these conclusions.

4.1 External and Internal Factors Overview

In order to better frame the discussion of individual factors throughout this chapter, an overview of the results are presented upfront. The case study data was analysed to determine the external and internal factors that influence the integration of DfRem into a company design process. Within-case analysis methods were influenced by Glaser and Strauss (1968)'s grounded theory 'coding' practices. Words, phrases and sections of text from documentation and notes taken during observations and interviews were coded to help identify emerging constructs, patterns and themes. From this analysis it was possible to determine which emergent factors had sufficient evidence to support them, and would therefore be included in the emerging theory. The identified external factors are summarised in Figure 17 and the internal factors are summarised in Figure 18.

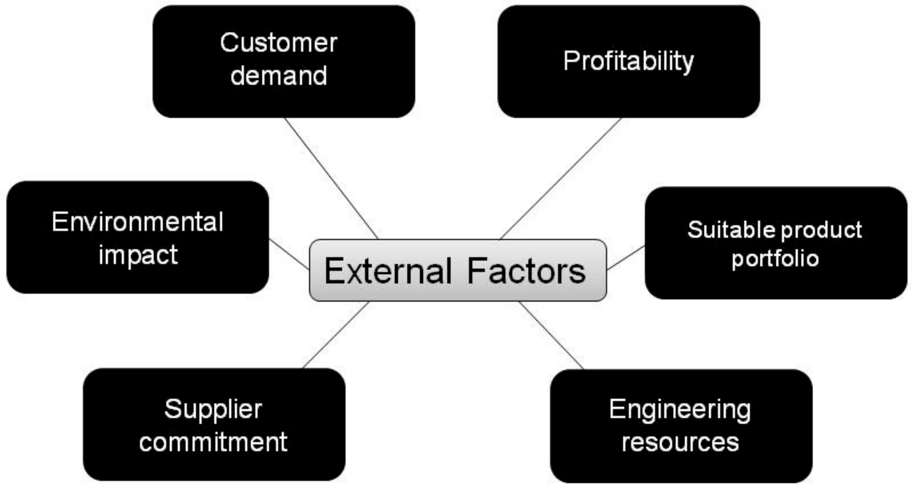


Figure 17: The external operational factors that influence DfRem integration, as identified through the case study research.

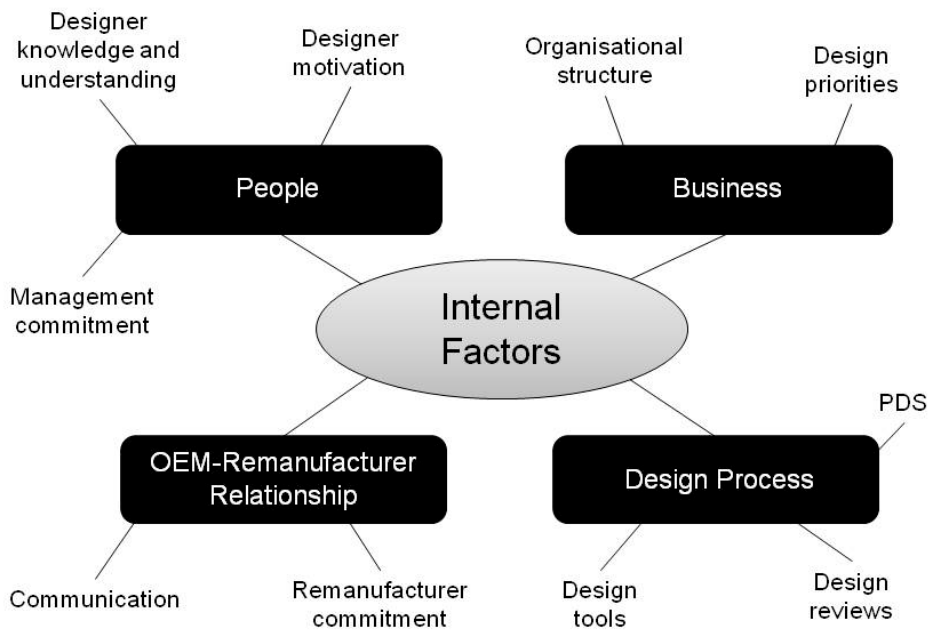


Figure 18: The internal operational factors that influence DfRem integration, as identified through the cases study research.

4.1.1 External operational factors

In accordance with research objective 1, the external factors that influence integration for each company were recorded and added to a complete list, with a view to painting a picture of the different reasons a company may decide to integrate DfRem into its design process. These external factors were determined either through indirect conversations with interviewees or through direct questioning about why the company had / would integrate DfRem. For example, designers at Company A discussed customer demand when being interviewed about their motivation, and managers at Company C answered engineering resources to a direct question about why they felt it would be difficult to begin DfRem integration.

It should be noted that not all external factors need be present / suitable for DfRem integration to be considered, and equally the presence of one or more positive external factors does not guarantee DfRem. To illustrate, interviewees at Company A did not cite engineering resources as an important factor, and Company C dumper trucks have suitable product characteristics for remanufacture (‘suitable product portfolio’). However, without *any* external factors i.e. incentives, it can be assumed that DfRem integration is very unlikely. The external operational factors illustrated in Figure 17, and described below, were either already driving a case study company to design for remanufacture, were hindering a case company’s ability to integrate DfRem or could act as a driver if the company’s macro-environment were to change in the future.

A brief description of each identified external factor follows.

Customer demand

Is there customer demand for remanufactured products? According to research from the automotive industry by Seitz (2007) and some case study interviewees from this research, customer demand can be expressed as either a market for remanufactured goods specifically, or a market for low-cost spares, which a company can provide through remanufacturing. The ‘customer’ who is seeking to extend the life of their product could be the product’s end-user (individual or organisation), a parent company or manufacturers higher up the supply chain. As designers and managers (and indeed all staff at an OEM) are often encouraged to put the customers’ needs at the forefront of their considerations, customer demand for remanufacturing is a clear indicator that DfRem is a worthwhile investment. Designing products so that they may be remanufactured to the highest standard and at the lowest cost will help satisfy this market segment.

Profitability

Designing a product specifically with remanufacture in mind will enhance the efficiency and effectiveness of the remanufacturing process, potentially reducing costs and increasing profit margins on each remanufactured product sold. As all OEMs are essentially profit driven, a design engineering department may be driven to integrate DfRem as a way of increasing company profitability.

Suitable product portfolio

In the mechanical/ electromechanical industry sector, products are typically well-suited to the remanufacturing process, without any specific design alterations, simply through their general product characteristics. The products are typically durable (predominantly metal) and of high-value. Therefore a company may hold a view similar to: 'the kind of products we make are well-suited to remanufacture, so it makes sense for us to maximize this opportunity with DfRem'.

Supplier relationship

In a globalised world, OEMs will almost never be responsible for the design and manufacture of all the components of a finished product. Therefore OEMs like the case study companies do not have complete control over the DfRem of all of their components and sub-assemblies. This means that much of a product's remanufacturability will depend upon what goes on at the suppliers end, and also the relationship/ level of control the OEM has over design decisions made by these suppliers.

Engineering resources

As DfRem is generally considered to be an additional, 'nice to have' design activity, the size of the design engineering team will influence both the time and resources available to design engineers to consider remanufacturing issues, and the team's connection to the company's remanufacturing and aftermarket services.

Environmental impact

Whilst very unlikely to be the sole reason behind DfRem integration (Ijomah et al, 2007; Seitz 2007), a company may be drawn towards DfRem through a desire to reduce the organisation's environmental impact and enhance the company's 'green credentials'. Because remanufacturing can often reduce a company's environmental impact (due to less energy and raw material requirements than a newly manufactured equivalent), a company may be motivated to include DfRem as part of its environmental management system or ecodesign strategy.

4.1.2 Internal operational factors

Unlike the external factors, the internal operational factors outlined in Figure 18 are directly relevant to the design engineering department/ team of an OEM (or other immediate stakeholders), and therefore are more within an engineering manager's control. These factors were identified through the case study research in accordance with research objective 2. Within this category of operational factors, the confirmed internal factors were then organised into sub-categories, which emerged during the coding and categorisation of identified potential factors. People factors are those which relate to the individuals involved in DfRem integration: their knowledge, thoughts, perceptions and behaviours. Business factors are those which were linked to the company as a whole: its organisation, culture and values. Design process factors are those which were found to be elements of the company's established product development practices and habits. And finally OEM-Remanufacturer relationship factors were those factors for which the remanufacturer was also an immediate stakeholder / participant.

People factors

Management commitment

The level of commitment from managers— both at top management and design engineering management level— will have an effect upon DfRem integration. Whilst design engineers are the individuals who will actually carry out DfRem activities, it is management who will make the important implementation decisions.

Designer motivation

This factor refers to how motivated design engineers are to carry out DfRem as part of their day-to-day work. In other words, how incentivised they are to design for remanufacture. Motivation could be led by a personal desire to improve remanufacturability, how important designers perceive DfRem to be within overall product development and the level of pressure from management and formalities in the design process.

Designer knowledge and understanding

This factor refers to the level of awareness, understanding and expert knowledge design engineers have of both the remanufacturing process and DfRem principles. This knowledge and understanding could be gained through education, training, experience, company documentation or through following the example of others in the workplace.

Business factors

Organisational structure

Organisational structure is a factor that may have an impact upon DfRem integration, as it will influence communication between teams or departments. Of course it is extremely unlikely that a company would alter their organisational structure purely to improve DfRem, but it is an important consideration nonetheless that will affect other management decisions, and can be used to explain current practices and perceptions within a company.

Design priorities

With each new product development, there will be ‘design priorities’: issues which are of significance or importance to ensure the new product is a success. Traditionally, these design priorities revolve around function and cost, i.e. meeting customer requirements and enabling the most efficient manufacturing process possible. End-of-life considerations will not be of top priority when designing a new product, because without desirable products which generate company profit, there would be no justification for new product development at all (Luttropp and Lagerstedt, 2005). However this does not mean that DfRem could never be considered important. Where DfRem lies in the (theoretical) ‘hierarchy’ of design priorities will have an impact upon ease of integration.

Design process factors

Product design specification (PDS)

The ‘product design specification’ (PDS) is a document developed at the early stages of product development, which outlines the specific requirements of the new product. These requirements could relate to size, weight, cost, ergonomics, environmental impact…and so on (Pugh, 1991). If DfRem principles can be included at the design specification stage, they will become a design requirement rather than a ‘nice to have’, additional consideration. Designers are expected to follow the specifications in the PDS document as closely as possible, however compromises and trade-offs can still be expected.

Design reviews

Design reviews are a common, formal element to the product development process. They are regular milestones in the process, meetings at which the different participants in new product development can come together to assess the new design against the original specifications. Design reviews are an opportunity for all aspects of the product design to be discussed, and, depending on the stage in the design process, amended. To what degree (if any) remanufacturability is considered during design reviews can have an impact upon DfRem integration.

Design tools

Design methods and tools are practices and applications which can assist designers at various stages along the product development process. For example QFD for specifications, brainstorming for concept generation, various CAD packages for detail design. Having remanufacturing considerations either included in existing design tools or the use of specific DfRem tools may enhance DfRem integration.

OEM-remanufacturer relationship factors

OEM-remanufacturer communication

This factor refers to the level, and the quality, of communication between the OEM (specifically design engineering) and the remanufacturer. Communication could include the sharing of data and design information, feedback about design-related remanufacturing issues or design engineering visits to remanufacturing facilities to gain a better understanding of the process. If design engineering and remanufacturing talk to each other, the need for DfRem will be better understood. Furthermore, DfRem will not be integrated 'blindly', but with an understanding of specific company requirements.

Remanufacturer commitment

For the relationship between OEM and remanufacturer to work, the remanufacturer must also be committed to improving product design. It may seem logical that the remanufacturer would be committed to more remanufacturable products, but it is possible that a remanufacturer will be unaware or uninterested in DfRem as they are accustomed to doing things 'the way they've always been done'.

4.2 Within-Case Analysis: Company A

4.2.1 Company A's current remanufacturing and DfRem activity

The large diesel engines produced by Location 1 (engineering and manufacturing facility) are mainly remanufactured at the Location 2 remanufacturing facilities, whereas engines manufactured in Location 3 are typically sent to another facility in France. At present it is only the cylinder heads of Location 1-produced engines that are remanufactured, although several other parts may simply be reused. Whole engines produced at Location 3 may be remanufactured. The key differences between the Location 1 and 3 engines is size and life in use- Location 3 engines are smaller with shorter lifecycles, which may mean that remanufacture is less economically rewarding.

Company A's parent company retains ownership of the returned cores and the remanufacturer (Location 2) is provided with the necessary design drawings. Company A has been remanufacturing its engines in some form or another for many decades. Design engineering provide the remanufacturer with full access to design drawings via an online database. Some OEMs (contractors) do not provide such information due to intellectual property sensitivity and competition concerns, for example if the contract OEM is itself contracted by another competing OEM. These products are remanufactured through reverse engineering, which means a sample product is disassembled and analysed to determine how it may be remanufactured and what spare parts will be required. Although not as effective as working from original drawings, years of experience means that the remanufacturer is confident in the reliability of this method.

Company A's products are naturally suited to remanufacture because diesel engines are of very high value (worth investing in reusing materials) and predominantly metal (able to withstand the remanufacturing process). The engines are mainly assembled manually, meaning fastening and joining methods are generally easy to disassemble in a non-destructive manner. Furthermore, it is important that such high value engines can be taken apart for regular maintenance, meaning they must be designed with disassembly in consideration. Crucially, remanufacture has proved a profitable route to market for the company. These are the reasons why the design engineers at Company A believe remanufacturing has 'always' been considered to some extent during the design and development phase.

In general, it can be said that Company A's products are designed with remanufacturing issues taken into consideration. DfRem specifications such as those regarding disassembly and additional material are outlined in the product design specification (PDS) document. For example, allowances for crankshaft dimensions, and the use of oversized bearings that can be replaced with smaller bearings by the remanufacturer. The PDS document is written by both design engineering and marketing, based upon established DfRem guidelines. Marketing tend to be in favour of DfRem as there is significant customer demand for remanufactured Company A engines and/ or low cost spares. Aftermarket will also have a say in the serviceability guidelines outlined in the PDS document.

DfRem is also part of Company A's 'design for environment' checklist, which is completed for each component design, in accordance with the company's Environmental Management System. This checklist must be signed off by a manager, and although not all features in the list must be satisfied for each component, the checklist is a way of ensuring issues such as

DfRem are at least taken into consideration. The design engineering staff are given some environmental training, however most DfRem knowledge is gained from experience and from other engineers.

Remanufacturability will also be assessed during the ‘serviceability audit’, carried out at a design review by aftermarket management (the company’s ‘remanufacturing liaison’). At this stage any design features that could hinder remanufacturability are flagged up and possible DfRem improvements are suggested. However, these audits are usually carried out at a later stage in the design process when any major changes to the product cannot be made.

The DfRem standards literature that is followed by Company A designers today was developed by the company many years before the parent company takeover. These standards are still considered suitable as the main design of the diesel engines produced today were developed in the 1980s. However, a common problem with such guidelines and booklets is that designers will rarely consult them, they end up ‘being put in a drawer and forgotten about’ (Lofthouse, 2006).

4.2.2 DfRem drivers and enablers

The decision to remanufacture (and therefore design for remanufacture) is very much driven by customer demand. Company A produce high value engines and their customers expect long life at an affordable price, as well as the provision of affordable spare parts. As a result, marketing endorse remanufacture and DfRem has become part of the PDS documentation (called ‘product objectives’ at Company A). Remanufacturing has also been found to be a profitable business venture for Company A, which drives DfRem activity, as well as the simple fact that diesel engines are naturally well-suited to the remanufacturing process. It makes sense for Company A designers to enhance this existing product attribute, especially as its designs do not require extensive alteration to become more remanufacturable.

Another DfRem driver at Company A is environmental impact. The parent company views sustainability as one of its core values. Remanufacturing and therefore DfRem are one way for Company A to enhance environmental credentials. In the company’s marketing material, remanufacturing is sold as a sustainable, ‘green’ activity that Company A is proud of, and this has an effect upon designers’ attitudes and perceptions of DfRem.

One thing that enables DfRem at Company A is the fact that the company has access to a wealth of knowledge and experience from their own history in remanufacturing and from its parent company, which has become highly competent in running a remanufacturing business over many years. Therefore it could be argued that Company A designers today have an advantage when it comes to DfRem integration.

The company's 'design for environment' checklist could also be considered an enabler as designers are expected to consider this throughout their design work, and at design reviews the checklist is used to demonstrate that issues such as DfRem have been considered. Whether DfRem has been achieved or not is decided by the designer and the manager who checks and signs the checklist. The checklist has the added benefit of aiding Company A in demonstrating it is achieving ISO 14001 environmental standards during audits. Annual renewal of ISO 14001 accreditation is important for company reputation.

Another key enabler is the presence of a 'remanufacturing liaison', a member of aftermarket management who is in communication with both remanufacturing and design engineering and is therefore in a position to relay DfRem feedback between the two parties and carry out serviceability audits. McAloone (2000) describes the need for an 'environmental champion' when integrating environmental considerations into the design process. This is a person who is knowledgeable of environmental legislation and design issues, is able to promote ecodesign and act as a consultant for environmental and design issues that arise during the design process. It could be said that Company A has a 'remanufacturing champion'.

4.2.3 DfRem barriers and challenges

Although Company A's products are designed for remanufacture, there are still a number of barriers and challenges that affect both the ease of achieving remanufacturability and the motivation to do so.

First of all, remanufacturing is of course not one of the top priorities in product development. When compared to other issues such as performance and cost, trade-offs can be expected. Some of the challenges Company A designers face, such as meeting the Tier 4 / Stage IIIB emissions targets[1], put strain on the presence of remanufacturable design features, for example additional material on cylinder heads. Trade-offs due to greater priorities is particularly an issue with (the smaller) Location 3 engines, which no longer feature sleeves and have stricter honing specs, making the remanufacture of these engines a greater challenge.

Considering physical challenges, there are some components which simply cannot be designed for remanufacture due to the demands of their functionality. For example the high tolerances, combined with high rates of wear of piston grooves, render these components not suitable for remanufacture. Some design features or new innovations can hinder remanufacturing, or at least create new remanufacturing challenges. For example, some engines the Company A remanufacturer (Location 2) receives from contract OEMs have welded pick-up pipes that are extremely difficult to inspect for cleanliness, whilst others can easily be disassembled. Other design changes can actually facilitate effective remanufacture. For example, a decision to add extra material to a part to save money on gaskets has given the remanufacturer greater flexibility for resurfacing that part.

In recent years there has been an increase of electronics in electromechanical products such as diesel engines. This was initially a problem for the remanufacturer, as this design trend makes engines very challenging to test. Electronic management systems now have immobilizers that stop an engine from running on a test rig, i.e. outwith a vehicle. However remanufacturing staff at Location 2 have been working to overcome this problem and now have two methods of testing engines that will disconnect or override engine immobilizers. 'Fooling' the engine into acting as if in-vehicle in particular required close OEM cooperation. At the same time, electronic programming can actually help remanufacture as cores can often be reprogrammed to required specifications. In physical terms, many engine models will be essentially the same, with the exception of one or two part numbers. The main difference is in the electronic programming- the engine management system. Location 2 remanufacturers are able to upgrade the management system or change it to better meet customer demand. Increase of plastics (less durable) and non-ferrous alloys (which are less resistant to cleaning), however, is an issue.

[1] US and EU emissions legislation is becoming increasingly stringent. Tier 4 (US) and IIIB (EU) were introduced in January 2011 and apply to 130-560kW diesel engines and require such engines to have reduced PM emissions of 90% and NOx emissions by 45%, when compared to the previous Tier 3 / Stage IIIA legislation.

Suppliers present another challenge to remanufacturability of Company A's engines as components supplied by third party companies will not generally be designed for remanufacture. There is little incentive for a supplier to carry out DfRem as they will not reap the benefits of the resold remanufactured engines.

Finally, there is currently no legislation that requires Company A to consider product end-of-life during the design process. The End-of-Live Vehicle (ELV) Directive, for example, only applies to on-road automotive products and there is no comparable legislation which applies to power generation or off-road equipment.

4.2.4 Internal operational factors that influence DfRem integration

Management commitment

No evidence was recorded at Company A to suggest that management commitment is preventing DfRem integration into the design process. Whilst design managers interviewed were clear that DfRem was not top of their priority list, it was a long-accepted part of the design process. Management had a strong influence on DfRem integration, defining product objectives and checking environmental checklists, for example. Therefore management commitment is clearly an important issue, but as DfRem is already in place at Company A, their 'commitment' was not considered a pressing issue in the minds of interviewees.

However, this does not necessarily mean that management commitment is no longer a relevant consideration, and reviewing interview notes does highlight some management commitment issues in Company A. Design management did not feel that improved OEM-remanufacturer communication was necessary, in complete contrast with the views of both aftermarket management and remanufacturing. This could suggest that a lack of commitment or enthusiasm from the design management is what would create barriers to such communication in the future.

Furthermore, there were some instances where engineering management displayed a lack of full awareness of the company remanufacturing process and DfRem external operational factors e.g. what parts are currently remanufactured or exactly how profitable remanufacturing is for Company A. This lack of awareness could impede upon management commitment if the benefits of DfRem integration are not fully understood.

Designer motivation

Design engineers working at Location 1, designing diesel engines for power generation, were the most motivated. They understood that there was customer demand for remanufactured products and accepted DfRem was part of their given tasks, as outlined in the PDS document.

However, in Location 3, where there are far greater technical challenges and contradictions which make DfRem integration more difficult, motivating designers appears to be a greater challenge. One designer interviewed made the point that although prompting from the remanufacturing liaison did motivate some DfRem activity, as the remanufacturer is not 'the customer', he did not feel the issues were particularly important. Major pressures such as Tier 4 / Stage IIIB emissions legislation and demand for increased engine performance simply demote DfRem to an inconvenience. Aftermarket at Location 3 cited designer motivation as a problem.

Location 2, although removed from the design process both geographically and due to limited communication, also mentioned motivation as an issue, suggesting it is a particularly significant factor in the company at present. Remanufacturing managers felt that designers were 'protective' of their designs, and did not like the idea that their creations could be 'tampered' with by a remanufacturer. Similarly, designers at Location 3 expressed some personal doubts over the feasibility and quality of some remanufacturing operations. A designer with a negative perception of remanufacturing and its capabilities will be less motivated to design for it. However, a way to improve this situation, according to interviewees at Location 2 (remanufacturing), is to have designers, or at least design managers, visit the remanufacturing facilities. Interviewees at Location 2 said that design managers who toured the remanufacturing process would often leave feeling confident in the capabilities of remanufacturing and often inspired to become more involved in DfRem.

Designer knowledge and understanding

Company A designers, in particular those working at Location 1, were fairly knowledgeable of the remanufacturing process and its benefits to the company. They were aware of DfRem principles from PDS guidelines and company literature, and had learnt how to apply these principles simply though experience. Designers interviewed may have found integrating DfRem challenging or inconvenient, but they did not feel that DfRem was a particularly difficult task from an intellectual standpoint. It was viewed as being no different to other expectations placed upon them such as ‘design for manufacture and assembly’ (DfMA); all covered by their engineering education. They did not receive specific DfRem training and did not feel the need for it.

However, reflecting on the case study findings, there are some issues regarding designers’ knowledge and understanding at Company A. Some designers interviewed expressed some mistrust of remanufacturing’s ability to bring modern, very high-performance engines back to an as-new condition, which would imply a lack of knowledge (and likely a lack of communication) of the latest remanufacturing technologies available to the remanufacturer.

Another concern that was highlighted during interviews with design management was the use of ‘historical data’ at Company A: the official DfRem guidelines published for use by Company A designers were written several decades ago. Although the basic engine framework has changed little over these years, a reliance on this historical information could possibly mean that designers are not fully informed of the most pressing DfRem issues facing Company A remanufacturing today, for example the increasing use of both electronics and plastics.

Organisational structure

The organisational structure of Company A was not raised as a barrier to DfRem integration in any of the interviews or correspondence for the case study.

Design priorities

Even in an organisation like Company A, that designs for remanufacture, remanufacturing is still considered to be low priority, and will often be compromised for more crucial product properties relating to function and cost, for example. However, DfRem is still considered to be of some importance or it would not be part of the design process. This is influenced of course by the external operational factors- the fact that remanufacture is a profitable business for Company A and the fact that there is customer demand for its remanufactured products. DfRem is also a small part of the company’s dedication to sustainability. The main threat to DfRem at present, in terms of design priorities, would appear to be the Tier 4 / Stage IIIB emissions legislation. As a legal requirement, Company A’s main focus today is upon reducing emissions and increasing the fuel efficiency of their engines. If a design change will contribute towards meeting legislation, but hinder remanufacturing, the change will most likely be made.

Product design specifications

A stand-out observation at the Company A case study was the fact that remanufacturing requirements are present in a project's 'design objectives', or product design specification (PDS) document. DfRem is allocated its own section in the document, which is written in collaboration with aftermarket (the remanufacturing liaison in particular). The whole document is also written in collaboration with marketing who, according to designers interviewed, are supportive of DfRem because they are aware of customer demand for remanufactured products. Designers at Company A accept DfRem as part of their everyday jobs because it is outlined in their product objectives. Of course, compromises are permitted and not all requirements in the PDS will be present in the final product, especially less important requirements like DfRem.

Significantly, both designers and aftermarket management considered the PDS to be a crucial factor in DfRem integration at Company A. Namely, those who are expected to carry out DfRem and those who have a particular interest in its success.

Design reviews

The attendance and content of design reviews was highlighted as a key area for improvement in terms of Company A's DfRem integration, by both design and aftermarket management. Presently, design reviews could be considered a time when DfRem is considered, as it is at design reviews that the 'design for environment' checklist is looked over for each component. Aftermarket attend design reviews and the remanufacturing liaison will carry out a serviceability audit, however this is currently too late in the design process to enable any real design changes. Nevertheless, these small steps towards integration have highlighted the potential in design reviews to bring DfRem considerations to the forefront, encourage discussion and act as an education experience for design engineers.

Design tools

Company A does not use design tools specifically developed for DfRem, with the exception of the guidelines literature produced many years ago that is still sometimes referred to today.

Designers and design managers interviewed struggled to envisage a DfRem specific tool or why it would ever be necessary. This is because at Company A DfRem is not viewed as a separate task, instead just one of the many normal considerations of the design process. Designers also do not view DfRem as a particularly challenging task, another reason for their lack of interest in design tools designed to make DfRem easier. Designers did however mention that CAD tools used in normal practice can assist in DfRem: ProEngineer enables designers to try out adding additional material (to allow for re-boring) and easily test the effects this will have upon the design.

Another tool that may enhance DfRem integration is Company A's 'Design for Environment' checklist, developed as part of the company's commitment to ISO 14001 (Environmental Management Systems). As well as environmental considerations such as 'material black and grey list' and 'coatings required', the checklist also asks the designer if he or she has considered 'Design for Remanufacture' and 'Design for Disassembly', amongst others. This checklist should be completed for every new component design and must be reviewed and approved by an engineering manager. This does not mean that every component will be designed for remanufacture (or should, as not every component will have the same end-of-life destination), but it is an assurance that the designer has at least considered the issue to some extent.

OEM-remanufacturer communication

Company A has made considerable steps towards OEM-Remanufacturer communication. Both aftermarket management and remanufacturing management felt that communication was key to improving DfRem integration at Company A.

The main method of communication between design engineering and remanufacturing is through the 'remanufacturing liaison', an aftermarket manager who is responsible for discussing remanufacturing issues with remanufacturing and relaying these back to design engineering. The information is mainly communicated through the liaison's involvement in the writing of the PDS, however the liaison will also encourage and remind designers to consider DfRem throughout the design process. Designers interviewed at Location 3 (where the liaison is based) cited this communication as their main motivator in considering DfRem.

However, the liaison himself felt that his role was actually hindering the most effective communication between the two parties; that it would be far more beneficial if design engineering and remanufacturing could be encouraged to communicate directly, and if remanufacturing could take a more active, direct role in the design process. There were also concerns of what would happen to communication links once the liaison left the company: at the time of the interview he was in the process of passing on knowledge to a group of aftermarket engineers. Furthermore, remanufacturing managers interviewed at Location 2, who were not closely linked to Location 3, expressed concerns that they were mainly communicating with staff from a non-engineering background, who would not fully appreciate DfRem issues (however the remanufacturing liaison did come from an engineering background). Having one individual link of any background in a large company does not amount to a great amount of quality communication.

Considering direct communication, management at Location 2 were able to describe several instances in which a design engineering manager had visited the facilities to talk directly with the remanufacturers and see the process in first person, and had been ‘converted’ to the benefits of remanufacturing and DfRem. Although for practical reasons this kind of communication would not be possible for all members of engineering staff, it is a good indication that more direct communication is noticeably most effective.

Of course, for effective, direct communication to work, the people involved have to be committed to the process. It is interesting to note that it was almost exclusively aftermarket management that called for better communication. Design engineering did not consider communication an issue because all Company A design drawings are readily available to remanufacturing through an online database. This would suggest that barriers to improved communication in the future may mostly be from design engineering. Managers interviewed at Location 2 agreed that the database did reduce the need for regular communication when designing the remanufacturing process for a new product; however they did discuss the potential benefits of improved design feedback. Nevertheless, the liaison felt that remanufacturing staff as a whole were not entirely committed to getting more involved in the design process, as discussed in the next section.

Another point of communication between the remanufacturer and the OEM (aftermarket) is during the making of the remanufacturing spec. This is a formal ‘living’ document that can be updated as the product design evolves. The reman spec is typically made after the product has entered the market, it must be approved by the OEM and the remanufacturer cannot deviate from this document.

Remanufacturer commitment

It may seem obvious that the remanufacturer would be committed to DfRem, and indeed managers interviewed at Location 2 did express an interest in the subject and a desire for products to improve, however their actual involvement in the design process may not be so simple.

According to the remanufacturing liaison at Location 3, as well as motivating designers to consider DfRem, getting remanufacturing involved in the early stages of the design process was also a challenge. The products being designed today will not be seen by the remanufacturer for years, possibly decades. Like many remanufacturers, staff at Location 2 are preoccupied with dealing with the issues of today, so attending design reviews for example would seem like an irrelevant task to them. This lack of forward-thinking is most likely to be due to time and resource constraints rather than ignorance, it should be noted.

4.3 Within-Case Analysis: Company B

4.3.1 Company B's current remanufacturing and DfRem activity

Although not normally referred to as 'remanufacturing', Company B's aftermarket services match the definition of this process, i.e. returning used pumps to original spec or better. On the company's website, services are described as providing *'OEM warranted parts to original or upgraded spec'*. This is carried out both by authorized contractors in other countries and at the service bay located within UK manufacturing facilities.

According to Company B's aftermarket brochure, the company's remanufacturing process involves the following stages:

- Consultation with the customer.
- Laser scanning of parts (for diagnosis).
- Analysis and 're-engineering'. Aftermarket has its own engineers who will create a manufacturing model and drawing of the pump. Typical improvements made during remanufacture include increased part strength, improved hydraulic design and upgraded materials.
- 'Rapid manufacture' (remanufacturing)

This process is guaranteed to provide the same quality as all Company B OEM parts and comply with ISO9001, with a warranty that matches that guarantee (a key indicator of remanufacturing quality).

Much of this work involves replacing worn parts with newly manufactured components, as opposed to carrying out reprocessing activities such as cleaning, re-boring and resurfacing; however there are occasions when such rework can be carried out for particular components. For pumps designed for the nuclear industry, the frequency of 'replace with new' may be due to the tighter tolerances which render reprocessing methods such as re-boring impractical, as well as tighter controls meaning nuclear pumps are typically treated on-site rather than at a service facility. For pumps designed for the oil industry, new components are most often chosen because reducing process downtime is crucial, and a 'quick-fix' is necessary.

Company B's pumps are well-suited to the remanufacturing process, being of high value (worth investing in) and made of durable materials (able to withstand both the remanufacturing process and multiple lifecycles). There are also several general 'design for maintenance' features which are typically found in Company B pumps, such as removable sleeves, which are beneficial to remanufacture. Design engineers are expected to consider the general maintenance and servicing of new products, and Company B pumps are designed for easy disassembly and access for maintenance. Design engineers are not specifically trained in meeting these requirements, instead these issues are considered a basic part of their day to day work, something that can be learned easily through experience.

However, Company B pumps are not *specifically* designed to enhance the effectiveness and efficiency of remanufacture. Design engineers are not incentivised to consider specific remanufacturing issues because there are currently no product specifications relating to pump remanufacture, and no formalised systems, methods or tools used by design engineers to enhance the remanufacturability of a product at the development stage. Design engineers interviewed were however able to demonstrate a basic understanding of DfRem principles.

4.3.2 DfRem drivers and enablers

A key driver to design for remanufacture at Company B would be the fact that aftermarket is the most profitable part of the business, suggesting that investing some time in ensuring pumps can be remanufactured efficiently and effectively may be worthwhile. Also, the increasing pressure upon the end users of Company B pumps to improve efficiency and reduce carbon footprint may begin to have an impact upon customer requirements for the end-of-life treatment of their purchases in the future, however environmental impact is not considered to be a DfRem driver at present.

Considering enablers, an advantage design engineers working at the case study site have is the fact that the aftermarket team and the service bay are located on-site. Although not currently in place, this proximity creates an opportunity to establish regular, quality feedback between the two parties.

There are also some opportunities for future DfRem integration into the Company B design process, based upon existing practices. Checklists used during design reviews could be adapted to include remanufacturing considerations. Also, the company 'Incident Control Report' system could be utilised to encourage feedback between aftermarket and design engineering, as well as continuous improvement of pump remanufacturability.

4.3.3 DfRem barriers and challenges

The incentive to design Company B products for remanufacture is perhaps not as straightforward as in companies operating in different industries. Whilst aftermarket services are a crucial part of Company B's business, there is no specific customer demand for remanufacturing services at the design specification stage. This is due to the nature of the oil and nuclear industry in general- orders are placed by 'Engineering and Procurement Contractors' that are removed from the end user, meaning they have little interest in the product's servicing or end-of-life treatment. Furthermore, these EPC customers often have very specific demands, leaving little room for 'additional, nice to have' features such as DfRem. As a result, DfRem is not normally included in the PDS and design engineers are not expected to consider remanufacturing issues specifically as part of their work.

The current organisational structure also creates barriers to DfRem. Design engineering and aftermarket are separate business units, and communication between the two parties is not regular or formally organised (for example aftermarket are not present at design reviews). The main reason given for this was the difference in speed of delivery: aftermarket must operate at a much faster pace, and being a separate business unit enables this. The Company B organisational structure also challenges the incentive to design for remanufacture, as there is an element of competition between aftermarket, who want to remanufacture products, and design engineering who usually prefer to sell a new product (as long as they believe it to be a good option for the customer).

Generally communication between the two parties was not deemed necessary; however some opportunities to exchange information that could improve the ease of servicing pumps may be missed. At present, any communication that does take place is not normally direct, instead it is usually through warranty personnel.

4.3.4 Internal operational factors influencing integration

Management commitment

Design management, who had an interest in the performance of the company as a whole, could see that DfRem could potentially be of benefit to Company B. However, without strong evidence of these benefits, managers were not prepared to dedicate time and effort to DfRem integration.

Reflecting on interview conversations with design management, it was clear that a problem with management commitment was their own lack of incentives. Questions regarding external operational factors were mostly answered negatively, and it became clear that design management lacked awareness of why Company B remanufactures its products. This may impact upon their commitment to DfRem integration. Furthermore, one design engineer and one aftermarket manager interviewed stated that managers were not interested in remanufacturing issues.

Designer motivation

Designers interviewed at Company B were upfront about the fact that they did not feel they had any incentive to design for remanufacture, as it was not something they were ever required to consider as part of the design process. Design managers agreed that they did not expect DfRem to be included as part of a designer's everyday work, and as a result designers do not feel that DfRem is particularly relevant to their individual jobs. This is not to say that designers did not appreciate the potential benefits of DfRem, indeed one designer interviewed said he felt passionate about environmental issues relating to DfRem, but in reality designers are busy people and understandably would not be prepared to dedicate time to an issue that was not part of their job description.

Aftermarket and remanufacturing were not fully aware of designer motivation issues, most likely because the two business units are disconnected at Company B.

Designer knowledge and understanding

It was difficult to determine the significance of designer knowledge and understanding in DfRem integration at Company B, because designers have never been expected to display DfRem skills. During interviews with designers, there was some confusion over remanufacturing terminology, but once definitions had been explained the designers showed an awareness of the remanufacturing process and its benefits, and said they felt that DfRem would not be a particularly challenging task should they be expected to carry it out. They expected that DfRem would not be dissimilar to considerations regarding pump maintenance, which they all had experience with, and they were also aware of the activities being carried out in the Service Bay below their offices and therefore had some inclination of what DfRem guidelines could be.

Organisational structure

Both aftermarket and engineering management agreed that the organisational structure of Company B is likely to pose challenges upon DfRem integration. This is because aftermarket and the various design engineering groups are treated as entirely separate business units (not an uncommon way to organise a business involved in many market sectors). This separation of the two routes to market became particularly apparent after a merger in 2008. This means that the two parties have a reduced awareness of each other’s activities, and reduced communication.

Furthermore, there was some discussion during interviews that the separate business units created an element of competition between aftermarket and design engineering. Aftermarket are keen to sell remanufacturing services, whilst design engineering would prefer to sell the customer a new pump whenever they consider this to be the best offer. This would reduce the incentive to design for remanufacture. However, remanufacturing management did not agree that there was any element of competition.

Also, the structure of the oil procurement industry as a whole has an impact on incentives to design for remanufacture, as discussed in Section 4.3.3.

Design priorities

Very demanding customer requirements (that do not include remanufacturing requirements) means that DfRem is very low down in the priority list at Company B. Top priorities include commercial drivers and meeting manufacturer's design codes. At present, the commercial benefits of DfRem for Company B remain an uncertainty (there is no solid data to prove DfRem would save the company money). Engineering management stated that until better evidence could be shown to them that DfRem would bring significant benefits to the company, it would remain a fairly low priority concern. A senior engineering manager stated that Company B design for function, design for manufacture and *then* design for service and maintenance.

Product design specifications

At present, DfRem is not included in Company B design specifications. Considering specifications, design managers cited the fact that their customers in the oil and nuclear industry are extremely demanding, providing design Engineering with long lists of very specific demands. This currently leaves little room for additional 'nice to have' issues such as DfRem.

The customers do not demand DfRem because they are not the end user- Company B original equipment customers will be Engineering and Procurement Contractors, and therefore do not take quite such a strong interest in servicing and end-of-life issues. They will not be the ones dealing with these issues later in the product's lifecycle, or paying for them.

Design reviews

Similar to Company A, design management at Company B raised the suggestion that design reviews could provide an opportunity for DfRem integration. One engineering manager said that if remanufacturing issues were ever considered at Company B in the present time, it would be during design reviews, although most likely as an 'extra consideration' towards the end of a meeting, if at all. He therefore felt that design reviews were the means for new designers in the company being able to pick up DfRem knowledge and awareness, from more experienced designers who would be raising such issues.

Interviewees from aftermarket were not able to comment on the significance of design reviews because, at present they do not attend such meetings, or have any input into decisions made during the design process. At present, this is unexplored territory at Company B.

Design tools

There was no evidence gathered during the design reviews that design tools would be expected to play a significant role in DfRem integration. This is most likely because the company would not treat DfRem as a separate, specialised task but more likely as just one of the regular design requirements.

OEM-remanufacturer communication

At present, there is very little communication between design engineering and aftermarket or remanufacturing at Company B. Design management felt that regular communication was not necessary as aftermarket has its own engineers working on the design of the remanufacturing process, and all design information is shared. Remanufacturing agreed that there was no strong need to communicate. However, interviewees from aftermarket management, who have an insight into both worlds (even if their connection to design engineering is limited), did feel that improved communication could possibly lead to more remanufacturable products and an improved remanufacturing process. A stated barrier to increased communication was the problem that designers and engineering managers operate from ‘ivory towers’ (their words) and are not interested in communicating with remanufacturing shop floor workers.

Remanufacturer commitment

The Service Bay management at Company B were clearly very proud of their home-grown remanufacturing process, which was in the process of expansion at the time of the case study. Management felt that Company B pump designs were very well suited to remanufacture already, and there were no real issues regarding DfRem. They were more interested in the enhancement and expansion of the remanufacturing process capabilities than the enhancement of product design, and were therefore not too interested in collaborating with design engineering on a regular basis.

However, aftermarket management, who on some level act as a link between the remanufacture and design engineering, did feel there was scope for design improvements in Company B. It is possible that management at the Service Bay do not recognise the need for communication due to the perception that if pumps are currently remanufactured to a satisfactory standard, then there is no need for improvements or changes to current system.

4.4 Within-Case Analysis: Company C

4.4.1 Company C's current remanufacturing and DfRem activity

Company C is not currently involved in remanufacturing. Whilst third parties are known to remanufacture or refurbish the company's parts for resale, and there is a second hand market for its products, the original equipment manufacturer (OEM) has no involvement or stake in these activities. Company C do offer their customers a service package that will enable them to prolong the life of their purchase, however servicing currently involves the replacement of worn parts with newly manufactured spares.

It has been noted that Company C's products, for example dumper truck axels, are suited to the remanufacturing process, as demonstrated by top competitors in the industry who are already profiting from remanufacture. Any move toward remanufacture at this early stage would require commitment from top management. A barrier for Company C is the cost of initial set-up, combined with the uncertainty of economic feasibility of such a business venture. The company requires more information about the business case for remanufacture before any decisions could be made. Due to the expected cost of remanufacture start-up, any future remanufacturing activity is likely to be carried out under a contractual agreement with an independent company.

Company C's products are not currently designed for remanufacture, for example components do not feature additional material that could enable surface skimming or re-boring. The obvious reason for this is that the products being developed today are unlikely to be put through a remanufacturing process. However, Company C design engineers are required to consider the serviceability of a new product, and therefore design for the simple, non-destructive disassembly of many components. This product characteristic would aid any future remanufacturing activity.

4.4.2 DfRem drivers and enablers

First of all, many of the components of Company C products are naturally suited to the remanufacturing process: they are durable enough to withstand multiple lifecycles and are of high value, driving the demand for a prolonged life in use. Although Company C does not currently remanufacture, or design for remanufacture, the company is led to consider it as a future possibility by the competition. Company C's top competitors are already operating successful remanufacturing operations and designing their products for enhanced remanufacturability, so Company C realise it is something they may have to move towards at some point in the future to remain competitive as a business.

One enabling feature of the Company C design process is the 'serviceability reviews', during which a design is reviewed in terms of its suitability for disassembly and servicing. This existing practice could be adapted to include remanufacturability issues. Also, the products being manufactured in the case study location are technologically stable- most of the design work carried out today involves the development and improvement of mature designs. This development work provides an opportunity for DfRem principles to be incorporated into Company C products.

Furthermore, although Company C design engineers and managers do not currently have experience of designing for remanufacture, the company does hold extensive knowledge of the disassembly and servicing of many components, e.g. transmissions, through the development of its aftermarket training centre.

4.4.3 DfRem barriers and challenges

The main barrier to design for remanufacture at Company C is the simple fact that the company does not currently remanufacture its products. Although 'proactive' DfRem— in anticipation of remanufacturing in the future— could be of benefit to the company, as long as the feasibility and/or timescale of remanufacturing set-up remains unclear, there is no strong incentive to begin designing for remanufacture now.

Another barrier is the fact that several of the Company C dumper truck's key components, for example the engine, are purchased from suppliers and are therefore not designed by the in-house team. These 'off the shelf' parts may be suited to remanufacture but Company C will have less control over DfRem in these cases. However, some supplied components are custom-made for Company C, and in these cases remanufacturability could be part of the design specifications.

If DfRem were to be integrated into the Company C design process, a challenge may arise from design priorities. Like all companies in this industry, Company C's main focus today is upon complying with Tier 4 / Stage IIIB emissions legislation whilst continuing to meet customer demands. There is currently no legislation demanding that manufacturers of off-road vehicles consider the end-of-life of their products, and therefore it is unlikely that remanufacture will be of top priority in any new product development. Ensuring remanufacturability when faced with design conflicts may become challenging in this case.

Another challenge to DfRem integration would be ensuring that design engineers and management feel able to carry out this task. Staff require some knowledge and experience of the remanufacturing process in order to understand how Company C products may be improved, and they also require both time and tools to carry out DfRem effectively. What makes this challenging is the fact that the design team in the case study location is small with little flexibility for including 'nice to have' design features, plus Company C does not have a history of carrying out 'DfX' in general.

4.4.4 Internal operational factors that influence integration

Management commitment

The possibility of remanufacturing at Company C is being discussed at a middle management level. Both design engineering and aftermarket managers interviewed agreed that remanufacturing could possibly enhance the company's competitiveness in the future. Although they had limited knowledge and experience of this field, they felt that if Company C were to go down this route, they would be able to become more committed to DfRem integration. One manager in particular was committed to integrating more DfX in general at

Company C, due to his experiences in previous employment. At present, DfRem is not a logical move when there is so much uncertainty around remanufacturing implementation. These managers felt that commitment had to come from Company C’s top management before they could realistically get involved. They said that top management commitment greatly relied upon the provision of greater evidence regarding remanufacturing’s benefits and logistics.

Designer motivation

Simply put, as long as there is no remanufacturing in place, there is no incentive to design for remanufacture. Designers interviewed had never considered remanufacture during their time at Company C, and were not expected to.

Designer knowledge and understanding

Because Company C has never had any involvement in remanufacturing, both design managers and design engineers have little knowledge or experience of the remanufacturing process, let alone DfRem principles. The terminology around remanufacturing was also unfamiliar to some interviewees, a common issue with remanufacturing in general. However, some managers and designers did have knowledge and understanding gained from experience working in other companies, or keeping up to date with the latest industry developments. Managers interviewed felt that their designers (and themselves) would require some more basic knowledge of the remanufacturing process, however the DfRem activity itself did not seem like a particularly unusual or challenging task to the designers interviewed.

Organisational structure

No strong evidence was gathered to suggest that organisational structure had an influence upon DfRem integration at Company C.

Design priorities

As DfRem is not on the agenda at present, of course it is not a priority in the slightest. However, design and aftermarket management interviewed felt that even if DfRem were to be integrated, it would still be of fairly low priority, when compared to requirements relating to function and cost, for example.

Product design specifications

Remanufacturing guidelines are not currently part of the design specifications, and will not be as long as there is uncertainty over remanufacturing implementation in general at Company C.

Design reviews

Designers interviewed at Company C also highlighted design reviews as a potential way to integrate DfRem into the design process. When discussing DfRem principles during the interview, designers recognised similarities between DfRem and their current serviceability audits', which assess new product developments for ease of maintenance and servicing. Ease of remanufacture could one day be assessed in a similar fashion.

Design tools

There was no evidence gathered to suggest that design tools are a significant factor at Company C, however the company is not at the stage yet where practical details such as CAD integration or checklists can easily be envisaged for DfRem. Also, one design manager mentioned that Company C does very little DfX in general, so it is likely that designers have less experience of using DfX design tools.

OEM-remanufacturer communication

This factor was not applicable at Company C; the company was not at the stage where communication between OEM and remanufacturer is relevant.

Remanufacturer commitment

This factor was not applicable at Company C.

4.5 Cross-case Analysis

The next step in Eisenhardt's multiple case study methodology involves 'searching for cross-case patterns', as a way to reduce researcher bias, and reduce the likelihood of reaching premature or false conclusions. Cross-case analysis involves selecting different categories, and looking for similarities and differences across the case study data. Miles and Huberman (1994) suggest the use of tables and matrices as a way of organizing this information in various ways, with a view to noticing patterns and new observations.

For this cross-case analysis, two kinds of comparisons were made. Firstly, two matrices were created to compare the identified external and internal operational factors of each case study company, and then a similar 'role-ordered' matrix was created to compare findings from different roles in each case study company: design management, designers, aftermarket management and remanufacturing management (see Appendix 2). For each comparison, evidence had to be provided for the presence of each factor, its significance and the reasons behind its significance in each company (or lack of). During this process, the researcher was particularly interested in across-board agreements and key differences between the case study companies, in particular between Company A, that designs for remanufacture, and Companies B and C that do not.

There were a number of originally identified operational factors that were eliminated at this stage, for example 'training' and 'use of historical DfRem data'. A factor was eliminated if it was clear it was only significant in one company (yet could not be attributed to DfRem integration maturity), or if the evidence to back up a factor was found to be weak, for example if the evidence was only recorded briefly from one individual in a case study, and could not be considered reliable. That is not to say that very useful data was never collected from a single individual. There were many instances where an interviewees particular role within the case company gave them a unique insight into that company's DfRem integration. On the other hand, when reflecting over some interview data is was decided that some 'evidence' was little more than throwaway comments, and was therefore not reliable enough to be included in the analysis.

The following sections will provide a summary of the insights made as a result of each cross-case comparison. These conclusions led to the definitive list of organisational factors and an understanding of their inter-relationships, as discussed in Chapter 5.

4.5.1 Cross-case analysis: external operational factors

Customer demand

Customer demand appeared to be a fundamental DfRem driver at all three case study companies: it was the primary reason given by Company A for DfRem integration, and lack of demand (or perceived lack of demand) was a primary barrier at Companies B and C. This would suggest that customer demand is one of the most basic, essential requirements for DfRem integration to be considered a feasible option. This is not surprising as all the case study companies were customer-focused, dealing with often very specific and customised requirements.

Profitability

One of the main similarities between Companies A and B, that operate in different industry sectors, was the fact that their aftermarket services were highly profitable, and a significant part of the overall business strategy. However, only Company A viewed this as a reason to integrate DfRem. Company B required more evidence that integrating DfRem would actually increase this profit, suggesting that 'profitability' in itself is not a sufficient driver to DfRem, and the real difference between Companies A and B was that designers and managers at Company A understood that DfRem could improve remanufacturing profitability.

Suitable product portfolio

Due to the selected case study population, all three case study companies manufactured products which could be considered 'naturally suited' to the remanufacturing process and market. This was cited as a reason to design for remanufacture at both Companies A and C, but was not a sufficient reason for Company B, indicating that suitable products alone will not drive DfRem if other factors act as barriers.

Also, the difference in attitude at Company B (where a suitable product portfolio was viewed as a reason not to design for remanufacture) would suggest that this external factor is a complex one which will depend upon the perceptions of individuals working within the system.

Engineering resources

This factor was only cited at Company C because Companies A and B are considerably larger. However, considering the fact that Company C are still a multinational with revenue of over $6 billion, this small difference could be an indicator that DfRem is only feasible for the largest design engineering teams working for industry leaders.

Supplier relationship

Only aftermarket management at Company A mentioned suppliers as a barrier to DfRem. Therefore, it is likely that a positive supplier relationship with regards to DfRem is a high integration maturity indicator, but also a factor that does not play a crucial role in the success of DfRem integration. From an academic point of view, however, it is also worth noting the situation at Company C, where suppliers often produce the most remanufacturable components. This is something academia should bear in mind when arguing the case for more DfRem in OEMs.

Environmental impact

A difference between Company A and Companies B and C was its interest in reducing environmental impact and promoting a 'green' company image, beyond meeting legislative requirements. DfRem was part of this strategy, although environmental impact was not the main driver for integration. Both Companies B and C indicated that environmental issues may become more pressing in the future, but at present do not drive DfRem. This difference in perspective may indicate that it is the companies that are more forward-thinking in terms of general sustainability are more likely to view DfRem as part of that strategy.

4.5.2 Cross-case analysis: internal operational factors

Management commitment

The farther back in DfRem integration maturity the case company was, the more management commitment was viewed to be an issue: Company A were least concerned by management commitment, Company C were most concerned. At Company A, design management's role in DfRem integration is essentially overseeing existing, agreed upon DfRem practices. At Company B DfRem depends upon design management deciding it is a worthwhile inclusion in the company design process and at Company C any remanufacturing or DfRem activity in the future will depend upon the decisions made by company top management, with design management 'waiting in the wings'.

Although the overall conclusion of the cross-case analysis was that management commitment was more significant at Company B, it is interesting to note that design managers interviewed at Company A did not seem personally any more committed to DfRem than managers at Company B. They still felt DfRem was of low priority. The difference between the managers at the two companies was that Company A managers had greater awareness of the benefits that remanufacturing brought to the company, and the customer demand for remanufactured Company A engines, and therefore were more willing to accept that DfRem is a worthwhile part of the design process.

Company A's remanufacturing management stated that managers who are able to view the remanufacturing process will tend to be more enthusiastic about DfRem. However Company B design management are working on the same premises as the UK service bay, and regularly pay visits when asked for advice by the remanufacturing team.

Designer motivation

Motivation was considered to be a significant issue at all three companies, but the actual level of motivation at each company differed. Design engineers at Company A were found to have considerably more motivation and incentive to design for remanufacture than designers at both Company B and C. Company A is the only case study company to have integrated DfRem into its design practices. However, this motivation is not because designers at Company A have a particular passion for remanufacturing, are especially keen to reduce environmental impact or have had extra DfRem education. In reality, designers working in such large engineering companies do not have such a level of control over the overall product design, and do not have the time to pursue additional, personal interests very often. Instead, the difference between Company A and the other companies is that they are *expected* to consider DfRem, through the PDS, design reviews and serviceability audits. For the designers working at Company B and C, DfRem is simply irrelevant to them. Another key difference between designers at Company A and designers at Company B and C was that Company A designers were fully aware of the remanufacturing process and its benefits to Company A as an organisation.

However, it is worth noting that although designer motivation was strongest at Company A, this was continually being challenged by other design priorities (such as emissions legislation) and designers' doubts about modern remanufacturing techniques.

Designer knowledge and understanding

None of the case study companies provided DfRem-specific training, and none of the designers interviewed for this research felt they personally required additional training to carry out DfRem. They were largely in agreement that DfRem, although in many cases a new concept to them, did not seem like a particularly unusual or challenging task for someone with a regular engineering education (which would most likely include the 'Design for X' concept) and design engineering experience. However, designers at Company C did feel they would like more general information on the remanufacturing process before being expected to incorporate remanufacturing issues into their work. Despite also having no experience of DfRem, Company B designers did not express this concern, most likely because they had a general awareness of the remanufacturing processes already happening at the Company B service bay. Although the designers at Company B are not involved in remanufacture, aftermarket is a large part of the business so naturally staff will be aware of this.

So, it would appear that a basic knowledge and understanding of the remanufacturing process is an essential requirement for DfRem. Findings from the Company A case study emphasize this: designers' motivation for DfRem was waning due to doubts over modern remanufacturing techniques, namely metal spraying. It is therefore important that designers' knowledge and understanding of the company's remanufacturing process is kept up-to-date.

Organisational structure

The organisational structure was considered to be of greatest significance at Company B, where aftermarket and design engineering are treated as entirely separate business units (and then design engineering is divided into a further number of business units). At first glance, Company A would appear to follow a similar model, as its remanufacturing is carried out at different locations under a different brand name. However, unlike at Company B, its aftermarket department, which deals with the sales of spare parts and product servicing, is not as far removed from design engineering as is the case at Company B. At Company B, the aftermarket department has its own engineers and its own suppliers: they are entirely self-sufficient. Not only does this reduce the likelihood of communication between designers and remanufacturing, according to some interviewees, it can also create a slight element of competition between aftermarket and new equipment sales. If design engineers feel they are competing against aftermarket for procurements, they will be less motivated to consider DfRem. However, this element of competition should not be overstated in the analysis: of course each department relies upon the other to ensure the company is successful as a whole.

Unlike other operational factors, organisational structure cannot be linked to DfRem integration maturity. This issue was only present at Company B, and is the result of top management decisions based upon the company’s industry, customers, culture, history etc. It is perhaps unlikely that a company would change its organisational structure to accommodate DfRem alone. As far as DfRem is concerned, the organisational structure could be described as macro-internal: it is part of the OEM and directly relevant to engineering design, but is outwith the direct control of engineering managers. Rather, it is something that any DfRem integration plan would have to work around.

Design priorities

Something all three case study companies had in common was that DfRem was low in their design priorities. Even at Company A, where DfRem has been integrated into its design process, managers agreed that they did not consider remanufacturing issues to be of high importance, and designers were willing to compromise DfRem features if they contradicted more important design issues such as functionality or legislative requirements. At Company C, not currently designing for remanufacture, management were sure that even if the company were to move towards remanufacturing in the future, DfRem would most likely remain a ‘nice to have’ inclusion in the design process. Being in the same industry sector as Company A (off-road vehicles), Company C is subject to similar priorities and the same emissions legislation that is causing DfRem considerations to be sidelined at Company A. Whilst Company B operate in a different industry sector, DfRem has as similar status in the company because there is no drive, from customers or top management, to prioritise it.

The fact that design priorities is an across-the-board factor, that affects companies with more mature DfRem integration as well as those at earlier stages of integration, implies that this is a very top-level challenge to overcome in DfRem integration. Of course, remanufacturing will never be top of a designer's priorities. However, it is clear that at Company A, DfRem is definitely an issue of some importance, because remanufacturing considerations are present in the PDS and designers are willing to at least consider such issues at some point during new product development.

As well as being a top-level challenge, design priorities is also a precarious or dynamic factor in DfRem integration. Due to the introduction of increasingly strict emissions legislation, Company A, the most advanced company with regards to DfRem integration, has recently been in a position where some of its products are becoming less remanufacturable in order to comply, as well as improve engine performance. So, as a low priority design issue, DfRem's place in product development can change dramatically as other design priorities change or are introduced. Also, often priorities are affected by factors outwith the company's control. For example, emissions legislation at Companies A and C, and customer demand at Company B. This means that often, where DfRem lies in the design priorities is not necessarily linked to how profitable remanufacture is for the company.

Product design specification

Only Company A cited the PDS as a significant operational factor, because designers and managers have experience of seeing DfRem be incorporated into these documents. DfRem in the PDS was across-the-board considered to have a high impact on DfRem integration in the company. This would suggest that the PDS is a high maturity indicator. It was also identified as a key difference between Company A, that designs for remanufacture, and the other two case study companies.

Design reviews

All three case study companies identified design reviews as an opportunity to improve DfRem integration. At present, both Companies A and C have a 'serviceability audit' included in design reviews, the difference being that at Company A this audit includes remanufacturing considerations, and is carried out by a remanufacturing liaison. At Company B, however, aftermarket management have no involvement in design reviews: this was highlighted as a key difference between Company B, which remanufactures but does not do DfRem, and Company A, which is already involved in DfRem. The reason this difference has been highlighted is due to the fact that design management at Company B cited design reviews as a high-potential route to better DfRem integration. Furthermore, the fact that an 'early stages' company such as Company C see design reviews as a possible entry route is another indicator that this factor has high potential.

However, it must be noted that aftermarket management at Company A stated that by the time a serviceability audit is normally carried out, it is too late in the design process to incorporate any new DfRem features into an engine design. Therefore if DfRem is to be better integrated through the use of design reviews, it must be included at as early a stage as possible. On the other hand, the reason that design management felt that DfRem in design reviews would be beneficial was because it would promote discussion and enhance the knowledge and understanding of designers, in particular those who were less experienced. So there could still be value to DfRem being discussed at the later stages of the design process.

Design tools

Company A was the only company to discuss design tools in any detail, and whilst interviewees were able to provide some evidence of the benefits of tools to DfRem (e.g. CAD models), designers interviewed did not feel design tools were a particularly important factor in DfRem integration, and did not express an interest in dedicated DfRem methods or tools. Instead, they preferred to simply consider DfRem alongside all other design issues, without taking considerable time over the activity.

Companies B and C also did not express an interest in dedicated DfRem tools, however admittedly neither company were at the stage where they would be seriously considering such matters. This would suggest that whilst there are some benefits in incorporating DfRem into existing tools- for example Company A's DfE Checklist- it is a high-maturity factor that does not play a crucial role in DfRem integration.

OEM-remanufacturer communication

As Company C do not currently have a remanufacturer to communicate with, it was only Companies A and B that could be compared for this analysis. OEM-remanufacturer communication stands out as one of the key differences between the two companies. Company A is in communication (albeit insufficient, according to some interviewees) and Company B is largely not in communication. Perhaps the most visible reason for this difference in communication is the presence of a remanufacturing liaison at Company A, who initiates and controls communication between the two parties. However, top management must have deemed this role necessary so perhaps the real difference between the two companies is top management commitment. Proximity / access to remanufacturing is clearly not a key issue as Company B design engineers work in the same building as their remanufacturing process, which is not the case at Company A. The real issues, as judged through the cross-case analysis, are management commitment to communication, how enabling the organisation structure is, and general attitudes and perceptions of remanufacture throughout design engineering (at Company B, design engineering did not believe that an increase in communication was necessary, which could cause major barriers to any future attempts to establish this).

Communication was one of the main issues cited by aftermarket at Company B, and one of the main areas for improvement cited by aftermarket at Company A, suggesting this factor is both significant and highly influential in DfRem integration.

Remanufacturer commitment

Remanufacturer commitment was only flagged as an issue by aftermarket management at Company A, however analysis of interview data from Company B remanufacturing would suggest that this is an issue both companies have in common. However, remanufacturing managers at Company A clearly had an understanding of DfRem and its benefits, and were aware of Company A's efforts to improve the remanufacturability of their products. This would suggest that with more top management commitment, any remanufacturer commitment problems at Company A could be resolved more easily than at Company B, where remanufacturing management are not committed to DfRem because it is not something they have ever had reason to consider— it simply isn't part of the company's agenda nor vocabulary. Hence, when confronted with the idea for the first time, it is unsurprising that remanufacturing management at Company B did not consider DfRem necessary, as they have been running a successful remanufacturing operation without it for so long. This factor is therefore likely to be linked to awareness and understanding of DfRem in general, across a whole company.

4.5.2 Role-ordered cross-case analysis

Design management

An essential difference between the design management at the three case study companies was that managers at Company A felt that in general DfRem is a worthwhile activity, as did Company C managers (in theory at least), whilst design management at Company B did not agree that DfRem is necessary for their products. Both Companies A and B currently operate successful remanufacturing processes, and develop products which typically suit remanufacture (valuable, predominantly metal), but the design managers at the two companies have interpreted these facts differently. The logic at Company B was that because its pumps are already remanufactured, there aren't any problems that need to be addressed through DfRem. Remanufacturing management at Company B were in agreement with this. Design management expanded on this opinion by saying that they would need more solid evidence of the benefits of DfRem to Company B before integrating it into their design processes— as there are no glaring remanufacturing issues at present, the tangible value of DfRem is currently unclear. In contrast, whilst Company A design managers were not overly enthusiastic about DfRem, there was a consensus that it is an activity that brings benefits to the company and is worth at least some attention during the design process.

This difference in attitude is possibly linked to the disparity in both the presence of DfRem external factors at the two companies as well as design management awareness of the factors. At Company A, design management were aware that there was customer demand for remanufactured engines, whilst at Company B knowledge of customer demand was clouded by industry 'middle men' and the distance between design engineering and aftermarket. Design managers at Company A are encouraged to consider environmental issues by corporate management, whilst this driver is not present at Company B.

Although design management at Company C echoed the opinions and attitudes of design management at Company A, the data collected on this subject at the company was mostly theoretical- managers were discussing how committed they *would* be to DfRem *if* Company C were to engage in remanufacturing activities in the future. Therefore, design management at Company C were unable to provide detailed comments on business or design process factors, and were not able to comment at all on OEM-remanufacturer relationship factors. They could however discuss people factors, suggesting that these factors are the most basic and essential to ensure improved DfRem integration.

People factors were also heavily discussed by design management at Companies A and B. Both groups were in agreement that designer motivation was a significant issue, much more so than designer knowledge and understanding which they felt was not a major issue— they were confident that their designers had the education and skills to intuitively learn how to implement DfRem principles into their designs, should they be required to do so. Company C management, on the other hand, felt that because Company C has had no involvement in remanufacture they and their designers would require some basic remanufacturing knowledge before undertaking DfRem integration.

Another factor that design management at both Companies A and B were in agreement on was that additional communication between themselves and remanufacturing was not necessary. This was in direct contrast to the aftermarket management of both companies, suggesting that management commitment to increased communication could create barriers in DfRem integration.

Although Company A did display some use of design tools to assist DfRem, none of the design managers interviewed at the three case study companies were particularly inspired or convinced by the idea of specialised DfRem tools, suggesting that in reality this commonly proposed solution in the literature could be one of the most challenging and least rewarding routes to improved DfRem integration. All design managers from the three companies were in agreement that DfRem was a low-priority design issue, and were therefore not interested in investing time and effort into complex methods or tools. On the other hand, design reviews were highlighted by design management at all three case study companies as a possible route to improved integration. The best way to integrate DfRem into a company design process will be the way that people working in the organisation are most willing to engage in.

Design engineers

The general impression gathered from interviews with designers from the three case study companies was that whilst designers will be the ones actually carrying out DfRem, they have less control or influence upon DfRem integration. Designers at Companies B and C, where management have not decided to integrate DfRem and remanufacturing considerations are not part of the PDS, were in agreement that they simply had no incentive to carry out DfRem, and as long as that were the case, other factors were of little interest to them. Motivation was one of the most important factors highlighted by designers at Company A—although these designers do have some incentive to design for remanufacture, the incentive is continually being challenged by other more pressing factors, as well as their own personal constraints such as time and scepticism of the remanufacturing process.

Designers from all three companies were in agreement that, once the basics had been grasped, DfRem did not strike them as a particularly challenging task that would require any more training or experience than other, similar DfX considerations. Motivation, rather than knowledge, was their key barrier. Company A designers were the only ones with any real experience of being expected to design for remanufacture, and their confirmations that DfRem is not unusually complicated reinforce the other two companies' designers' opinions on the matter.

None of the designers interviewed expressed strong opinions regarding management commitment, however this factor is unlikely to be of great concern to designers who are themselves not motivated or interested in DfRem. This makes management commitment a difficult factor to gauge the real significance of.

One of the key points that marked Company A designers as different from the other two companies was their general awareness of DfRem external factors. They understood the Company A remanufacturing process and the purpose it serves to the OEM. This in turn helps them understand and accept the benefits of considering DfRem during their design work

Aftermarket management

Only aftermarket management at Companies A and C had strong opinions on people factors relating to design engineering (management commitment, designer motivation and knowledge & understanding). The aftermarket managers at Company B were too removed as a business unit from design engineering to have any awareness of these issues. Aftermarket at both Companies A and C were aware of designer motivation issues in their respective companies; Company A because aftermarket is in fairly regular communication with design engineering and at Company C because the company's case study location team is relatively small and therefore in closer contact with one another. Aftermarket management at Company

A in particular had direct experience of struggling to motivate designers to treat DfRem issues as important.

However, what aftermarket managers at Company A and B did have in common was their feelings that OEM-remanufacturer communication was an area for improvement in their respective companies. Of all the interviewees, aftermarket management are likely to have the greatest insight into this issue, as they often act as a bridge between remanufacturing and design engineering, even if in companies such as Company B that link to design engineering is limited. Also, the fact that a company which already has some communication between design engineering and remanufacturing (Company A) feel this factor could be further improved suggests that effective communication is a high-maturity factor.

Only Company A aftermarket management were able to comment on the potential benefits of including DfRem in the PDS and design reviews, as they were the only group who had any experience of being involved in this activity. Having experience of these factors, they are largely in agreement with design engineering that these factors can play a significant role in DfRem integration.

Remanufacturing management

This cross-case analysis was only applicable to Companies A and B, which had remanufacturing management to interview.

There was a stark contrast to the interviews with remanufacturing management at both of these companies. Company A remanufacturing managers had some links to design engineering, whereas Company B remanufacturing managers did not, other than the occasional consultation. Because of this difference, only Company A remanufacturing had an awareness of design engineering issues such as designer motivation and management commitment, and were even able to suggest solutions (remanufacturing tours), implying there could be tangible benefits to OEM-remanufacturer communication. Furthermore, Company A remanufacturing managers were interested in increased communication, whereas, like the company’s design managers, Company B remanufacturing management did not feel this was a relevant issue. This would suggest that the barriers to communication— and indeed DfRem in general— stem not just from a lack of commitment from design engineering, but a company-wide lack of enthusiasm, understanding and information about the potential benefits of DfRem.

4.6 Summary of External Operational Factors

Below is a summarised description of the identified external operational factors and their significance to DfRem integration.

Customer demand

Customer demand for remanufactured products was highlighted as a strong DfRem driver. Company A cited customer demand as one of the primary reasons for integrating DfRem, and both Companies B and C cited lack of direct customer demand as a reason against DfRem integration. However, in the case of Company B, there was clear evidence that remanufacturing was a successful part of the business, highlighting that the clarity of linkages and general awareness of this demand is just as important as its actual presence.

Profitability

Alongside customer demand, the profitability of remanufacture was highlighted as a key DfRem driver, and was also cited as a main motivation to design for remanufacture by Company A. However, opinions expressed by interviewees at Company B highlighted the importance of remanufacturing profitability, but also the knowledge that DfRem will increase this profitability. Without this evidence, Company B was reluctant to consider further DfRem integration.

Suitable product portfolio

Manufacturing in an industry that produces products naturally suited to the remanufacturing process (i.e. high value, durable, etc) could be viewed as a basic DfRem driver. Company A engage in remanufacturing because diesel engines are suited to the process, and feel that it makes sense to further enhance the remanufacturability of their products in order to optimize the process. Company C is also beginning to express an interest in remanufacture and DfRem because it is aware that its dumper trucks are ideal candidates. On the other hand, suitable products could also act as a deterrent to DfRem integration. At Company B, the fact their pumps can already be successfully remanufactured is seen as an indication that DfRem is not necessary.

Engineering resources

Smaller companies and smaller design teams will face more challenges if attempting to integrate DfRem. Limited time and resources for DfRem, on top the reduced likelihood of remanufacturing investment, de-incentivised design engineering at Company C. Although larger companies A and B also cited lack of time as an issue, it was not due to such physical constraints.

Supplier commitment

Suppliers were found to create additional complications to DfRem integration. Company A was unable to convince suppliers to design for remanufacture, reducing the overall remanufacturability of its products and reducing the overall benefits of DfRem in general. Company C had less incentive to design for remanufacture because many of the most remanufacturable parts of its products were provided by suppliers, often purchased 'off-the-shelf'. It is important to remember that large mechanical / electromechanical OEMs are very rarely responsible for the manufacture of all components in their products.

Environmental impact

Although not the strongest external factor, and most unlikely to ever drive DfRem integration on its own, the desire to reduce environmental impact certainly motivates Company A to design for remanufacture. This is a core value of the parent company which has filtered down to designers and managers. Knowing that they are contributing to the company's environmental sustainability helps employees take pride in their work.

Environmental issues (beyond legislation compliance) are not so highly valued in Company B and Company C, mainly because neither company has felt a strong demand from their customers for more environmentally friendly products. Therefore, any discussion around DfRem integration at these companies is unlikely to be driven by environmental impact at present, but it is quite possible this will change over time.

4.7 Summary of Internal Operational Factors

Management commitment

Management commitment to DfRem integration was identified as a significant internal factor. Without managers on board, very little action is likely to be taken. In all three case study companies, design managers were open to the idea that DfRem could bring benefits to their design process, yet were able to provide reasons against integration, or improved integration in the case of Company A.

Designer motivation

Designer motivation was identified as a major barrier to DfRem integration. At both Companies B and C, designers interviewed said that they simply had no incentive to consider remanufacture during their work as they were not required or requested to do so. At Company A motivation was a more complex issue, with some designers evidently motivated and others less so, due to issues such as time constraints and scepticism of the remanufacturing process. There are clearly different levels of designer motivation as a company progresses in integration maturity.

Designer knowledge and understanding

Although detailed technical knowledge of DfRem was not considered an issue at Companies A and B, this internal factor has been included in the research because designers at Company C felt they would require more basic knowledge and understanding of remanufacturing and DfRem before they felt confident they could include it in their design work. This, plus information gathered at Company A's remanufacturing facility and also scepticism issues raised at Company A would suggest firstly that designer knowledge is a maturity-based issue, most important at the early stages of integration, and secondly that knowledge and understanding of *the company's* remanufacturing process and its capabilities is perhaps more important that general technical DfRem knowledge.

Organisational structure

Although design managers are unlikely to be able to control the structure of the organisation, it is a potential issue which they may be able to overcome. This factor mainly refers to the 'distance' between design management and both aftermarket and remanufacturing, which was highlighted as an issue in Company B.

Design priorities

Design priorities refers to how important DfRem is considered to be by the company as a whole, and in particular design engineering, based upon its values and other important issues such as function, cost and legislation. All three case study companies admitted that DfRem would never be a top priority for them, and in some cases other priorities, such as emissions legislation, could actually compromise DfRem design features. It is also possible that where DfRem lies in the design priorities is due to a lack of understanding about the benefits DfRem could bring to the company.

Product design specification

The presence of DfRem considerations in the company product design specifications (PDS) was highlighted as a significant internal operational factor, as it helps ensure that DfRem becomes part of a designer's day to day work. Company A, who have already taken steps towards DfRem integration, was the only case study company to include such considerations in its PDS, highlighting this factor as a key difference between companies that design for remanufacture, and those that do not.

Design reviews

'Design reviews' was an internal factor that was identified as a key area for opportunity by all three case study companies. Many interviewees felt that these meetings, which may already involve 'serviceability audits' provided an opportunity to increase DfRem discussion and share knowledge and experience amongst designers. However, experiences shared at Company A highlight the importance of the timing of these discussions— too late in the design process and few changes can be made.

Design tools

Design tools were not considered to be of high importance by any of the case study companies. Company C lacked experience to comment, but Companies A and B expressed no interest in DfRem-specific tools. However, this factor has been included in the research because evidence was found in Company A that incorporating DfRem issues into some existing tools such as CAD and checklists can be beneficial.

OEM-remanufacturer communication

Communication between the design engineering team and the remanufacturer was flagged as a particularly significant factor. Both Companies A and B, who currently remanufacture, had interviewees who strongly felt communication between the two parties should be improved to ensure that the most pressing and current DfRem issues are being adequately addressed. However, not all stakeholders agreed that communication was an issue at these companies (it was an idea primarily promoted by aftermarket managers), suggesting that this cooperative factor may be one of the most challenging to improve.

Remanufacturer commitment

As well as design management commitment, if cooperation between the OEM and remanufacturer is to be successful, remanufacturing must also be on board. Although it would seem obvious that remanufacturers would wish to see more remanufacturable products, information gathered from Companies A and B would suggest that the issue is more complex when remanufacturers are too pre-occupied to consider the far future of their business, or feel content with the success of their current remanufacturing process.

4.8 Data collection and analysis process: reflection

The external and internal operational factors were identified through a process of interviews and observations at three case study companies, followed by the use of case study reports to improve the reliability of the information that was gathered. The case study notes were then coded to identify operational factors occurring in the data, both priori constructs and emergent. A series of tables were then used to ensure the evidence to support each identified factor was sufficiently robust. This process resulted in a clear and concise list of both external and internal operational factors that were found to influence DfRem integration.

There were a number of challenges to this process. Conducting semi-structured interviews with design engineering staff in particular proved challenging, mainly because these groups were less accustomed to expressing their views and experiences of remanufacturing and DfRem. The approach to these interviews was improved over time, taking care to ask similar questions in different ways to get the most thorough and accurate responses possible, and ensure the purpose of the research was explained effectively. It was also important to strike the right balance when writing case study reports, to ensure that all crucial information was contained to be verified, yet the reports were concise enough to encourage informants to respond promptly.

However, there were also a number of advantages to the process. For example, Eisenhardt's methodology allows for 'opportunistic' alterations to the research design when conducting case studies. Originally, aftermarket managers were not included in the case study protocol; it was interviewees at Company A Location 1 that suggested this group would be worth interviewing due to their unique insight into both engineering and remanufacture. Aftermarket managers proved to be some of the most informative interviewees for this research.

The use of evidence tables also proved to be a highly effective way of improving the reliability of the research results. One of the challenges of analysing the qualitative data was ensuring the researcher's perceptions and bias did not influence results, and that the evidence for each operational factor was sufficiently robust. The use of evidence tables highlighted these issues and added extra rigour to the data analysis process.

4.9 Chapter Summary

This chapter has presented the research findings which correspond to research objectives 1 and 2: the identified external and internal operational factors which influence DfRem integration. The factors have been categorised and discussed individually, drawing on evidence gathered from the three case study companies. The factors identified at each case study company have been presented, followed by a discussion of the cross-case analysis which determined the final research findings.

However, it is of little benefit to consider each of these operational factors in isolation of one another, and therefore the next research objective required an understanding of the relationships between them. These relationships will be discussion further in the next chapter.

5: Research Findings: Mapping Integration

The previous chapter outlined the external and internal operational factors that were found to influence DfRem integration in the three case study companies. This chapter now expands upon those findings to include the identification of the relationships between the different operational factors, and the subsequent development of a DfRem integration network model. This chapter will also explain how the research findings and model were validated.

5.1 Understanding Relationships

5.1.1 Importance of understanding relationships

The previous chapter outlined how this research has identified a number of operational factors which can influence the integration of DfRem into a company design process. However, if this research is to have any real value, a simple listing of operational factors will not go far: we also need to understand how these factors are linked to one another in order to understand 'DfRem integration' as a whole. According to Georgiou (2006) a holistic approach is called upon when 'treatment of a problem through the isolation of its constituent parts is rejected for being too reductionist' and too involved in the short term rather than long term goals of the business. The author felt that if a company were to address one of the identified factors in isolation, for example gaining remanufacturer commitment, the outcome would likely be insignificant. Not only is it important to consider all the relevant operational factors that could influence the company's DfRem integration, it is also of value to understand how these factors are linked to one another.

Product design can be described as a 'human-activity system', meaning that factors influencing DfRem are not likely to stand alone; they will be linked in one way or another. It was therefore important that this research was advanced through the development of a

‘DfRem Integration Network’ model. An understanding of the relationships and priorities between various factors will enable OEM design teams to view the bigger picture, aiding a more effective approach to decision making with regards to DfRem integration.

5.1.2 Theoretical background

The network model was influenced by ‘soft systems thinking’. Soft systems are social systems which, like DfRem integration, cannot be so easily defined due to the different viewpoints, motivations and interactions of those involved. Instead, soft systems models are about analyzing these complex systems in a way that enables us to understand this diversity of perspectives (Checkland, 1981, Mingers and White, 2010, Wilson, 2001). This is true of DfRem integration: the different stakeholders interviewed for this research (the designers, the engineering managers, the aftermarket managers and remanufacturing managers) all had differing opinions on the importance of DfRem and how it could be better integrated into their own roles within the company. Viewpoints and priorities also differed depending on the level of DfRem integration maturity of the case study company.

Soft systems diagrams show a network model of linked factors, with arrows indicating the direction of influence. Diagrams may also display ‘feedback loops’, in instances where two factors are found to influence one another in a self-reinforcing nature (a ‘chicken and egg’ scenario). Like soft systems thinking, this research was concerned with ‘a whole’, rather than ‘the whole’. The network diagram does not cover the whole organisation; instead it is centred around design engineering activities and the design process within an organisation. The research has particularly focused upon ‘internal’ operational factors, which have been defined as those factors within the direct control of a design engineering team. As can be seen from the list of operational factors (e.g. remanufacturer commitment), at times these direct influences extend out to other stakeholders, namely aftermarket and remanufacturing.

The development of the integration network model was also influenced by Blessing and Chakrabarti’s (1999) Design Research Methodology (DRM). This methodology is concerned with the description of a desired product design situation, through identifying networks of influencing factors. Such models should illustrate a likeness to something that exists in reality (e.g. DfRem integration), but is restricted to only some aspects of that reality depending on the model’s purpose (in this case, design engineering and the immediate stakeholders). DRM models show influencing factors which can be observed, measured or assessed. ‘Key factors’ are identified as having several influences and are therefore usually the most useful to address; they can often be considered the ‘root causes’ of a problem. ‘Success criteria’ are those factors which are ‘top of the network’, with most lines of influence leading towards them. These factors can be considered the ultimate goals of the project. They tend to be long-term and ideally should be measurable (Blessing and Chakrabarti, 1999).

The network model does not illustrate strict ‘cause and effect’ like many systems diagrams; instead it illustrates influences and linkages, as identified through the three case studies. As this is exploratory research, and DfRem integration is still a little understood subject, strict cause and effect could not be determined from these three case studies alone: further testing and longitudinal study is required to create such assertions. Furthermore, as all organisations are both complex and different from one another, the factors that will best lead to improved integration will differ from one company to another. The network model does not provide a straightforward checklist of steps to success, instead it offers companies a portfolio of options and considerations when integrating DfRem, and an understanding of how these factors are linked to one another. Like soft systems thinking, this research has been about exploring how problems regarding DfRem integration may be alleviated, rather than straightforward problems solved (Checkland, 1981). How the model will provide this understanding will be discussed in greater detail in the following sections.

5.2 Relationship Analysis

Relationships between the identified operational factors were determined using evidence from the case study interview information. Firstly two relationship matrices were completed to identify simply which factors are related to one another. A ‘relationship’ was considered present if interviewees, observations or documentation had provided evidence that one factor was responsible (or partly responsible, or significantly influential) in the measurement of another factor. Interview data was the most common source of such information, often from responses to ‘why’ questioning such as ‘why is DfRem included in the PDS?’ or ‘why is there currently no communication with the remanufacturer?’

The first relationship matrix (Table 9) identified where relationships were thought to be present. Each relationship was assigned a ‘strength’ rating of strong, medium, or weak. These evaluations were of a qualitative / subjective nature based on both the amount of evidence gathered for the particular relationship, and the amount of emphasis placed on the relationship by the sources of that evidence. This method was considered more effective than simply counting the number of times evidence for a relationship occurred. To illustrate, when designers at Company A were asked why they considered remanufacturing issues in the design process, they cited both design tools (a checklist) and the design specification document as motivators. However, far greater emphasis was placed on the importance of design specifications, whereas design tools were only mentioned as having a minor influence upon the designers' motivation. Therefore, these relationships were noted as 'weak' and 'strong' respectively.

The format of the relationship matrix was taken from the relationship matrix found in a QFD 'house of quality', in which relationships between customer requirements and engineering requirements are evaluated. The difference with this relationship matrix was that operational factors were evaluated against each other in order to determine a relationship network, or systems diagram. Like QFD, the relationship strengths were allocated a numerical rating of strong: 9, medium: 3 and weak: 1. Although these 'scores' should be read as subjective and non-definitive, they do generate some interesting observations. According to the matrix, customer demand is the most influential external factor, followed by profitability. This concurs with the overall impression provided by case study interviewees. Of the internal operational factors, OEM-remanufacturer communication was found to be the most influential factor, followed by both management and remanufacturer commitment. This would strongly suggest that it is the relationship and collaboration between the two parties that is crucial in ensuring improved integration. As for those internal factors that are influenced by other factors, designer motivation was found to be the most highly dependent, followed again by management commitment and OEM-remanufacturer communication. The fact that OEM-remanufacturer scored highly on both axes suggests it is a particularly significant factor.

The second relationship matrix (Table 10) took the findings from the first, and recorded which case study companies had provided evidence of which relationships. Evidence for relationships was recorded in a similar manner to the external and internal operational factors: coding of the case study notes when explicit references to relationships between factors were made. For example, there was considered to be a relationship between management commitment and OEM-remanufacturer communication because design managers at both Companies A and B stated that they were not interested in increased communication between their design teams and the remanufacturer; and because remanufacturing and aftermarket management at the two companies cited lack of interest from design managers as one of the main challenges to increased communication from their perspectives. As case study companies were selected to represent different stages of DfRem integration maturity, it was to be expected that not all relationships would be present at all three companies.

This information was then fed into a more detailed relationship table which was used to record the details of the relationship and the evidence gathered to support it, in a similar style to the Miles and Huberman (1994) matrices used during within-case and cross-case analysis of the operational factors. If the connection between two factors could not be sufficiently explained through case study data, the relationship was removed from the matrices and therefore excluded from the final network diagram. This was an important activity for ‘shaping hypotheses’: an evidence matrix helps to ensure that any relationships included in the model are not merely coincidental or based on the author’s assumptions. The evidence detailed in this large-format matrix is outlined in the following section.

Table 9: Relationship Matrix 1, which was used to allocate relationship strength rating across operational factors.

INFLUENCE →	Management commitment	Designer motivation	Designer K&U	Organisational structure	Design priorities	PDS	Design reviews	Design tools	OEM-reman communication	Remanufacturer commitment	
Customer demand	○	○				◉					15
Profitability	○	○			○						9
Suitable products		○									3
Environmental impact		△			○						4
Engineering resources	○	○									6
Supplier commitment					○						3
Management commitment	■				○				◉		12
Designer motivation		■									0
Designer K&U			■								0
Organisational Structure				■			△		○		4
Design Priorities	○	○			■		○	△			10
PDS		◉				■					9
Design reviews			○				■				3
Design tools		△						■			1
OEM-reman communication	◉	◉	○						■		21
Reman commitment							○		◉	■	12
	21	35	6	0	11	10	7	1	21	0	

Relationship Key

◉ Strong relationship = 9
○ Medium relationship = 3
△ Weak relationship = 1

Table 10: Relationship matrix 2, outlining the sources of evidence for each relationship.

INFLUENCE →	Management commitment	Designer motivation	Designer K&U	Organisational structure	Design priorities	PDS	Design reviews	Design tools	OEM-reman communication	Remanufacturer commitment
Customer demand	B	A B				A				
Profitability	B	A B			B					
Suitable products		A B								
Environmental impact		A B			A					
Engineering resources	C	C								
Supplier commitment					A C					
Management commitment					A B				A B	
Designer motivation										
Designer K&U										
Organisational Structure							B		A B	
Design Priorities	B C	A B C					A B	A B		
PDS		A C								
Design reviews			A B C							
Design tools		A B								
OEM-reman communication	B	A	A							
Reman commitment							A		A B	

Evidence Key

A = Company A
B = Company B
C = Company C

5.2.1 External operational factors relationships

Design engineering departments do not typically have control over external operational factors. Some such as customer demand are linked to the external market, whilst others such as environmental impact are most often determined by the company's top strategic management. Therefore, a study of the relationships between external factors and their influence upon other aspects of the organisation was outwith the unit of analysis for this research. However, as well as influencing the overall decision to design for remanufacture, it was found that the external factors did have an influence upon several of the internal operational factors specifically. In particular, customer demand and profitability were found to be highly influential, two factors which designers are generally encouraged to put to the forefront of design decision-making. Each external factor influence that was identified through the case study research is outlined below.

Customer demand influences management commitment and designer motivation

Both designers and management are encouraged to put the customers' needs at the forefront of their minds when making decisions and developing new products. Also, the design specifications designers are required to follow are typically based upon customer demands (for example, though the use of QFD).

Designers at Company A's Location 1 understood that DfRem was important because customers wanted remanufacturable products, and were therefore largely willing to include this as part of their product development work. When asked why they designed for remanufacture, customer demand was the first reason given by designers and engineering management.

On the other hand, whilst there is clearly customer demand for remanufactured Company B pumps (the profitability of the sector demonstrates this), the incentive of customer demand is not passed on to the company's design engineering departments. This is because newly manufactured pumps are typically purchased by an 'engineering and procurement contractor' (EPR) on behalf of the end user. These EPRs do not have a vested interest in maintenance or servicing and therefore do not demand DfRem in the design specifications. Company B engineering managers and design engineers were therefore only vaguely aware of customer demand for remanufactured pumps, and not at all aware of any demand for *remanufacturable* pumps: the linkage between the two was missing.

Furthermore, customers' very high demands for performance, low cost and so on can put great pressure upon designers, leaving little room for 'extra' or 'less important' considerations such as DfRem. Unlike its Location 1 facilities, Company A's Location 3 has less flexibility in its design decisions because the main customer— the parent company— could be described as 'internal'. The 'customer' can therefore be extremely demanding of its colleagues with regards to high performance, reducing the incentive to prioritise design for remanufacture. Designers at Location 3 stated that they were increasingly finding that they simply do not have time for DfRem.

Engineering management at Company B expressed a similar problem with regards to DfRem integration. The company is in the business of providing bespoke pumps to their customers, and as a result specifications tend to be very detailed and demanding. As mentioned above Company B's initial customers do not demand DfRem. This means that even if Company B were to recognise the benefits of DfRem to their company, there is no guarantee that there would be room in the design process for such a non-customer driven specification.

Customer demand influences PDS

Product design specifications are formulated to ensure that the new product meets technical requirements and customer requirements, often determined using methods such as QFD. When discussing a typical example, designers at Company A Location 1 explained that the PDS was written in collaboration with the marketing department, who prioritise customer demands. As there is known customer demand for remanufactured Company A products, marketing support the inclusion of DfRem requirements in the PDS.

Profitability influences designer motivation and management commitment

As management are concerned with the health of the business as a whole, and are more aware of the overall financial position of the business, aspects of the business which are most profitable will be given greater attention. Similarly, designers are encouraged to prioritise company profitability, as well as the customer's demands mentioned above. If remanufacture generates considerable profit for the company, designers can more easily see *why* they should be including remanufacturing considerations in their work.

The designers at Company A Location 1 stated during interviews that they did not have a personal problem with including DfRem in their work; it made perfect sense to them because remanufacture was known to be a profitable part of the parent company's business. Design managers also noted that aftermarket in general was very profitable, and could therefore see the logic in DfRem from that perspective.

However at Company B, aftermarket services, which includes remanufacture, is more profitable than the sale of newly manufactured equipment. Despite this fact, management at Company B said they were not committed to DfRem due to a lack of clear evidence that investing in DfRem would result in *increased* profitability of their existing (highly profitable) remanufacturing practices. This insight therefore highlights the difference between profitable remanufacture and profitable DfRem.

Suitable product portfolio influences designer motivation

A suitable product portfolio, i.e. if the company produces typically remanufacturable products, was found to influence designer motivation, but not always in the same way. At Company A Location 1, designers interviewed stated that they were willing to design for remanufacture as they understood that their products were good candidates for the remanufacturing process. It 'made sense' in their view, and as the diesel engines are already highly suited to remanufacture, they did not view DfRem as a particularly challenging or troublesome task.

On the other hand, one of the main reasons design engineering interviewees at Company B gave for not feeling the need to design for remanufacture was the fact that their pumps are already successfully remanufactured. Because design work at Company B mainly involves taking an established framework and customizing it to customer requirements, there was the view expressed that any maintenance and end-of-life treatment issues have already been dealt with and are no longer a concern.

Environmental impact influences designer motivation

Many designers are personally motivated to reduce their company's environmental impact, or at least can appreciate that sustainability is an important issue worth investing time and effort in. If designers understand that remanufacture and DfRem is contributing to the reduction of their company's environmental impact, they may be more incentivised to invest this time and effort.

Designers at Company A Location 1 in particular had a clear understanding that remanufacture is part of the parent company's sustainability strategy, and contributes to the company's green image. This was cited as another incentive to design for remanufacture. Interviewees at Company B, however, did not feel the same connection between remanufacture and environmental impact, and they also did not feel that environmental issues were a concern of their customers. This reduced their incentive to consider DfRem.

This relationship was marked as 'weak', because environmental issues were not considered a key incentive to design for remanufacture, and sustainability was considered less important than customer demand and profitability.

Environmental impact influences design priorities

Reducing environmental impact, whether it is a core business value or a legislative requirement, may boost the perceived importance of DfRem, provided the company has linked remanufacturing to environmental responsibility.

Designers and design management at Company A Location 1 prioritised DfRem in part due to the parent company's 'green' company values, and also to maintain ISO 14001 (environmental management systems) accreditation. However, design management at Company A Location 3 and Company C pointed out that there is no legislative requirement to carry out DfRem (for example the ELV Directive does not apply to off-road equipment), which renders the issue less important when compared to other environmental issues such as emissions output.

Engineering resources influences management commitment and designer motivation

The three case study companies included in this research could all be considered 'large', profitable OEMs operating in a global marketplace. However, even amongst these large companies, relative size of their design engineering teams was found to influence management commitment and designer motivation, for practical reasons.

The design team working at Company C's facilities was considerably smaller than that of Companies A and B, and managers felt this was unlikely to change in the future due to the current economic climate. Designers interviewed stated that they simply do not have the flexibility or the time to accommodate additional concerns such as DfRem: they must focus solely on meeting immediate customer requirements. Management interviewed also felt that there was little sense in considering ‘proactive DfRem’ as, although Company C’s top competitors are benefiting from remanufacture, the company is still considerably smaller in comparison and management do not envisage remanufacturing being established at Company C in the foreseeable future.

Supplier relationship influences design priorities

In a typical remanufacturing process, it is common for some used parts to be replaced with newly manufactured parts. There could be a variety of reasons for this: the part is too worn to be returned to as-new condition and no alternative remanufactured part is available; the particular part is not suitable for remanufacture (e.g. due to very high tolerances); or it is simply cheaper to replace with new. Therefore, the suppliers of these new parts coming into the remanufacturing process can have a significant impact upon the cost of remanufacture, which in turn will impact upon the profitability of the process as a whole.

Spares purchased from suppliers are typically very expensive. Furthermore, aftermarket management at Company A explained that a problem with remanufacture is the newly manufactured spares being ordered are often of a different size to that of manufacture (e.g. an oversized piston) and in smaller quantities. This drives up the cost, and if remanufacture is less profitable, DfRem has less influence on design priorities.

Furthermore, aftermarket management at Company A Location 3 expressed concerns that the company has been unable to convince its suppliers to design for remanufacture. This issue reduces the overall remanufacturability of Company A’s products, and again makes DfRem seem a less beneficial, worthwhile task to be prioritised within the company.

Another similar issue raised by aftermarket management at Company C was the fact that many of the most typically remanufacturable components of their dumper trucks, for example the engine, are not designed or manufactured by Company C but instead purchased ‘off-shelf’ from suppliers. This further reduces Company C’s remanufacturing control, and, according to interviewees, would reduce DfRem’s priority.

5.2.2 Internal Operational Factor Relationships

Whilst understanding the influence of external factors is important for making assessments of the context surrounding DfRem integration in a particular company, the relationship analysis primarily focused upon the relationships between internal operational factors, as these are the factors which design engineering can control. Each internal factor relationship that was identified through the case study research is outlined below.

Management commitment – design priorities feedback loop

Although design priorities are largely determined by external factors such as customer requirements and profitability, on a day-to-day basis they can also be determined by how committed design managers are to pushing DfRem issues during the design process. If design management consider DfRem issues to be of low priority, they will have less inclination to promote its integration into the design process and devote less time and effort into ensuring new products are suitable for the remanufacturing process. How management prioritise DfRem may be partly due to attitudes and perceptions: engineering managers at Company B simply did not feel DfRem was important to their product development projects.

At the same time, design priorities may also influence management commitment, for example managers at Company A had to give precedence to design issues relating to emissions legislation in order to meet legal requirements for their engines. This notably reduced their commitment to DfRem, which was regarded as a lower-priority issue.

This relationship was noted as a feedback loop, as the relationship works both ways. The higher priority DfRem is, the more committed managers will be. However at the same time, the more committed managers are to DfRem, the more they will promote DfRem as an issue to be prioritised in the design process. The reverse therefore would also be true: low management commitment will lead to low design priority and vice versa.

Management commitment – OEM-remanufacturer communication feedback loop

Evidence gathered from the case study research suggests that OEM-remanufacturer communication and management commitment influence one another in a ‘feedback loop’. Improved communication between the two parties may influence management’s awareness of important and pressing DfRem issues, increasing their commitment to DfRem integration. On the other hand, regular and effective communication is reliant upon design managers’ commitment to the DfRem cause in the first place.

Design management at Company B were not especially interested in formal DfRem integration because they were not aware of any particular need to do so— from their perspective there are no pressing DfRem issues to be addressed in Company B's products. Design management also did not feel there was any need for improved or more DfRem-focused communication between themselves and remanufacture for the same reasons. Whilst this may be the case (indeed remanufacturing management largely agreed, with some disagreement from aftermarket management), without communication, how could a design manager know for sure that there are no DfRem issues to be addressed?

Organisational structure influences design reviews

The company organisational structure may influence design reviews in terms of who is present and therefore what issues are covered during these meetings. Because Company B's organisational structure means that aftermarket and the various branches of design engineering are completely separate business units, representatives from aftermarket and remanufacturing are not present at design reviews: indeed they are not involved in any aspect of the design process as it is outwith their business scope. This will reduce the chances of DfRem issues being raised at these meetings, as no one present has a particular interest in the needs of remanufacturing.

Organisational structure influences OEM-remanufacturer communication

How the organisational structure places design engineering and aftermarket services in relation to one another can have an effect upon how easily remanufacture communicate with design engineering. Case study findings from Company A suggest that remanufacture's first point of communication with the OEM side of the business is with aftermarket services, most specifically warranty personnel. If aftermarket is treated as a completely separate business unit they themselves may have little communication with design engineering, creating a wider gap in communication. This was found to be the case at Company B, where there is very little communication between design engineering and aftermarket and even less so directly between remanufacturing and design engineering.

Design priorities influence designer motivation

Designers have a lot of issues to juggle when developing a new product, and some are going to be prioritised over others. Issues regarding function and cost are normally of high priority, and will take precedence over less crucial issues such as DfRem. How important remanufacturing issues are considered to be by the company as a whole may influence how motivated designers are to consider it as part of their design work: if it is very low priority it is most likely to be viewed as a 'nice to have', non-essential task that can be traded off. It may also be considered an inconvenience to busy designers with many other issues to cover.

Designers at Company A are presently very preoccupied with Tier 4 emissions legislation, as well as the drive to continually improve engine performance (a key customer demand). This is particularly the case for Company A Location 3 designers, who during interviews gave the impression of being more exasperated by DfRem than their Location 1 colleagues. The tighter tolerances imposed upon them means that DfRem features (such as adding extra material) that may be in conflict with these requirements, making DfRem a more complex and less rewarding task for designers. Furthermore, as one Company A designer stated, 'remanufacture are not the customer', and designers are encouraged to prioritise the customers’ needs.

Company C is also very focused on Tier 4 legislation, therefore it is likely that this company would face similar challenges if it decided to integrate DfRem.

Design priorities influences design tools

As discussed in previous chapters, much of the DfRem literature published today has focused upon the development of DfRem-specific design tools, yet there is very little evidence that such tools are used in industry. None of the case study companies used DfRem-specific tools, and when asked why this was the case, design management at Companies A and B stated that DfRem is simply not important enough to warrant a specific (and presumably time-consuming) design tool. However, the only evidence of DfRem issues being integrated into design tools was found at Company A: DfRem was assessed during the use of 3D CAD tools and also during the use of Company A’s environmental checklist tool. This is because Company A is the only company in this study to have prioritised DfRem to the extent that it is mandatory to at least consider remanufacturing issues.

Design priorities influences design reviews

The research found that how high or low DfRem is in the company or project design priorities can influence the prominence of DfRem issues at design reviews. Although Company A would still class DfRem as a low-priority issue, it is considered important enough to be a mandatory consideration. This means that a ‘serviceability audit’ is carried out during at least one design review throughout the product development process. Design management at Company B, however, stated that although DfRem issues may at times be raised during a design review meeting, they are likely to be very low down on the agenda and therefore addressed very late on if at all.

PDS influences designer motivation

The general impression given by designer interviewees at all case study companies was that they would not be motivated to integrate issues such as DfRem into their work simply for personal reasons, instead they would be motivated to consider DfRem if it was expected of them as part of their job or the projects they have been assigned. In other words, if designers are *asked* or *expected* to do DfRem, they would be most motivated to do so (although they may still consider it an inconvenience, see for example ‘design priorities influences designer motivation’). One of the main ways that a designer may be asked or required to consider DfRem is through the product design specification (PDS) document.

Designers interviewed at Company A stated that one of their main motivations for considering DfRem was its inclusion in their projects’ ‘product objectives’ i.e. PDS. The PDS for their current project at the time of interview featured a section on accommodating the remanufacturing process, and designers stated that although they may not always fulfil every requirement, having DfRem outlined in the PDS ensured that they were motivated to at least consider each requirement.

Design reviews influences designer knowledge and understanding

Design reviews were identified at all three case study companies as an opportunity to motivate designers to consider DfRem issues during their design work. Design reviews in general provide a key opportunity for various issues to be raised and acknowledged, and for discussion between experts, representatives, managers and designers. This also provides designers with a framework in which to gain more information about the company’s remanufacturing process and the DfRem challenges the company is currently facing.

Of the three case study companies, Company A was the only one to currently include any formal DfRem considerations in their design reviews. Designers at Company A cited the presence of aftermarket (a remanufacturing liaison) at some design reviews to be a key motivator for them, because during these reviews the liaison will put pressure upon them to make changes or consider particular issues. They stated that if it wasn’t for these reminders and pressure, they would be more likely to allow DfRem to slip to the back of their minds and become more easily compromised. However, the liaison felt that designers could be even better informed if actual representatives from remanufacturing were present at these meetings, and therefore able to provide first hand insight into the process.

Although not formally included in their design reviews at present, engineering management at Company B also cited design reviews as a potential opportunity to introduce designers to the concept of DfRem, allowing more experienced staff to raise issues regarding remanufacturability and for less knowledgeable designers to learn from them and understand how to take these issues on board. However, at present, remanufacture is not typically on the agenda at Company B design reviews.

Similarly, designers at Company C spotted a potential opportunity in design reviews, as they recognised that the ‘serviceability audits’ carried out during design reviews at present could be adapted to include DfRem issues in the future. They cited these serviceability audits as a main motivation for considering design issues regarding general product maintenance.

Design tools influences designer motivation

Design tools did not seem to have a very dominant role in DfRem integration at Company A (the only case study company to use them at all for DfRem). However, in the one instance that a DfRem design tool was discussed (the ‘design for environment checklist’), it was found to have some influence upon motivation. Designers at Company A Location 1 cited having DfRem on the checklist as being a further reason why they considered DfRem, on top of its inclusion in the PDS. Although designers did not *have* to address everything on the checklist, they are expected to at least justify why a particular feature has not been accommodated.

OEM-remanufacturer communication influences designer motivation

Designers’ motivation may be influenced by how aware they are of the DfRem issues currently affecting the company’s remanufacturing operations. Motivation may also be influenced by how often designers are prompted to consider DfRem as part of their design work. This is linked to OEM-remanufacturer communication. A problem identified in this research is that remanufacture has very little influence when compared to factors such as legislation or demanding customers, and so without hearing from the remanufacturer it is easier for a designer to forget or dismiss their needs as unimportant or 'nice to have'. Communication could increase pressure on designers as it helps DfRem be perceived as more relevant and significant.

At Company A, one aftermarket manager acted as a ‘remanufacturing liaison’. He was in regular communication with the remanufacturer, and communicated their requirements to design engineering, putting pressure on designers to accommodate for the most crucial DfRem requirements of the time. Designers at Company A Location 3 cited this communication as a main motivator for carrying out DfRem.

OEM-remanufacturer communication influences designer knowledge and understanding

As well as motivating, communication may help designers to learn of the most current problems and challenges facing their remanufacturer. If designers gain a better understanding of what their own remanufacturers do, this may enable them to create better DfRem solutions.

Company A Location 1 has less formal communication with the remanufacturer in comparison to the Location 3 head offices; possibly as the ‘remanufacturing liaison’ for Company A is based in Location 3. Although designers at Location 1 had good knowledge of remanufacturing and general DfRem principles, they were slightly less aware of the remanufacturing capabilities of their own engines, or what parts were currently remanufactured. This may have an impact upon how they go about designing for remanufacture.

Managers interviewed at Location 2 (remanufacturing facilities) were aware of this issue, and provided anecdotes of designers being, in their opinion, very closed-minded about the possibility of their designs being remanufactured. Interviewees at Location 2 were also able to discuss examples of times when the attitudes of design managers had been changed by a visit to their facilities, to see the remanufacturing process and learn about it first-hand. It is possible that if designers were able to have more direct engagement with remanufacturing then their knowledge and understanding could also improve, allowing them to make more informed DfRem decisions.

Remanufacturer commitment influences OEM-remanufacturer communication and design reviews

For a two-way dialogue between design engineering and remanufacturing to be successful, both parties have to be enthusiastic and willing to talk.

During interviews, management at Company A Location 2 said they would like a better dialogue about design issues, as did some aftermarket management at Company B. However, according to the Company A remanufacturer liaison, remanufacturer commitment is still a barrier to effective communication, as well as design engineering commitment. For example, according to the liaison, remanufacturing management are not interested in attending product development design reviews themselves, despite this being an opportunity for them to raise DfRem issues. This is because the products being developed today will not enter the remanufacturing process for several years, and are therefore not of immediate concern to the remanufacturer, possibly due to time constraints and lack of long-term vision. At present, remanufacturing are represented at design reviews by aftermarket management, not remanufacturing management.

Although aftermarket management at Company B expressed a need for improved communication, remanufacturing management did not feel the same way, as the remanufacturing process is already a successful operation.

5.3 The Network Model

Figure 19 presents the network model which was developed from the results of the relationship analysis. It has been designed to be clear, simple and easy to understand at a glance. It is expected that any manager referring to the model would also have access to more detailed information on what each factor means and how the factors are linked to one another.

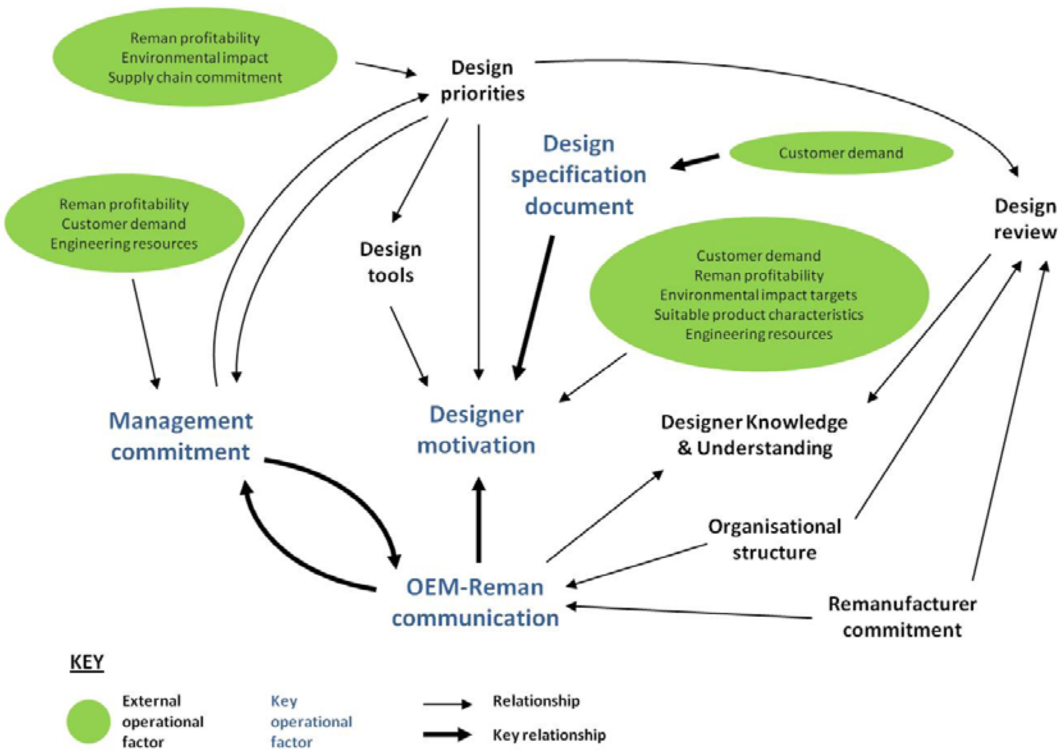


Figure 19: Network model, illustrating the relationships and linkages between operational factors.

In the model, a green highlight indicates an external operational factor, with the specific factors listed inside. All other text in the model describes an internal operational factor. Arrows indicate a relationship, and the direction of the arrow indicates the direction of influence, for example that 'organisational structure' influences 'OEM-remanufacturer communication', which in turn influences 'design motivation'. There are two instances in the model where arrows are displayed in both directions (see Figure 20). This illustrates a 'feedback loop', where both factors have an influence upon each other. This means that a positive influence is self-reinforcing (Georgiou, 2006). For example, increased communication keeps managers better informed of the importance of DfRem issues, which can lead to them becoming more committed to DfRem integration. If managers are more committed to integration, they may be more likely to improve their communication with the remanufacturer.

In the model, four internal factors have been highlighted in blue: product design specification, management commitment, designer motivation, and OEM-remanufacturer communication. The development of the model revealed that these four factors appear to be at the core of DfRem integration: these factors were the most strongly emphasised by key informants during data collection, and were confirmed as most important during model validation. In other words, these are the factors that can be interpreted as the key objectives in DfRem integration: the need for committed managers and designers who are both motivated and able to carry out DfRem through relevant design specifications and quality communication with the remanufacturer. In following with the Design Research Methodology, which influenced the structure of this model, the four internal operational factors highlighted in blue would be defined as the ‘success factors’ (Blessing and Chakrabarti, 1999). These factors are usually long-term goals which reveal the purpose of, in this case, DfRem integration. How a company can arrive at this position may be determined by their reading of the model as a whole: perhaps the company may choose to enhance communication with the remanufacturer, include DfRem in the PDS, and so on.

Two of the core factors can be classified as the ‘people’ factors, for which it is not possible to create the ideal situation without taking the more tangible, practical steps of other factors (one can include DfRem on a design review agenda, but it is not possible to create ‘designer motivation’ out of thin air). However, Design Research Methodology also states that the success factors should be measurable. These identified success factors, in particular ‘management commitment’ and ‘designer motivation’ are subjective and difficult to measure. Blessing and Chakrabarti (1999) state that if success criteria cannot be measured, then the nearest factors should be measurable. In the case of this model, the two other internal operational factors which were highlighted as highly significant both during data collection and model validation were ‘PDS’ and ‘OEM-remanufacturer communication’. These two factors could be considered measurable.

It was important to isolate the external factors because these are outwith the design engineering department’s direct control. By making these two distinctions in the model, the model becomes more readable and provides better guidance. A design manager can see what external factors they may have to consider, what overall goals they should be aiming to achieve and a portfolio of factors in between which, at the company’s discretion, may be utilized to help achieve better DfRem integration.

This model provides a holistic view of DfRem integration, based upon the three case study companies which took part in the research. It does not provide a clear roadmap to improved integration, or a checklist of actions to guarantee improved integration. Because organisations will have differing external factors, cultures, resources etc, it is down to the companies’ own judgment to decide what steps they wish to take to enhance DfRem integration. For example, one company may refer to the model and decide that communication must be improved and DfRem must be included in design reviews, whilst a smaller company with existing close ties to its remanufacturer may instead decide that their designers need more knowledge and understanding and choose to focus on that aspect of the model.

Although design engineering does not have direct control over external factors, the model may also encourage them to learn more about these factors. There were several instances during case study interviews, at all case study companies, where a member of design engineering staff was unsure about external factors, profitability and customer demand in particular. The model may highlight instances where staff should be better informed of this information. For example, awareness of external factors such as profitability and customer demand was found to influence designers' motivation to carry out DfRem.

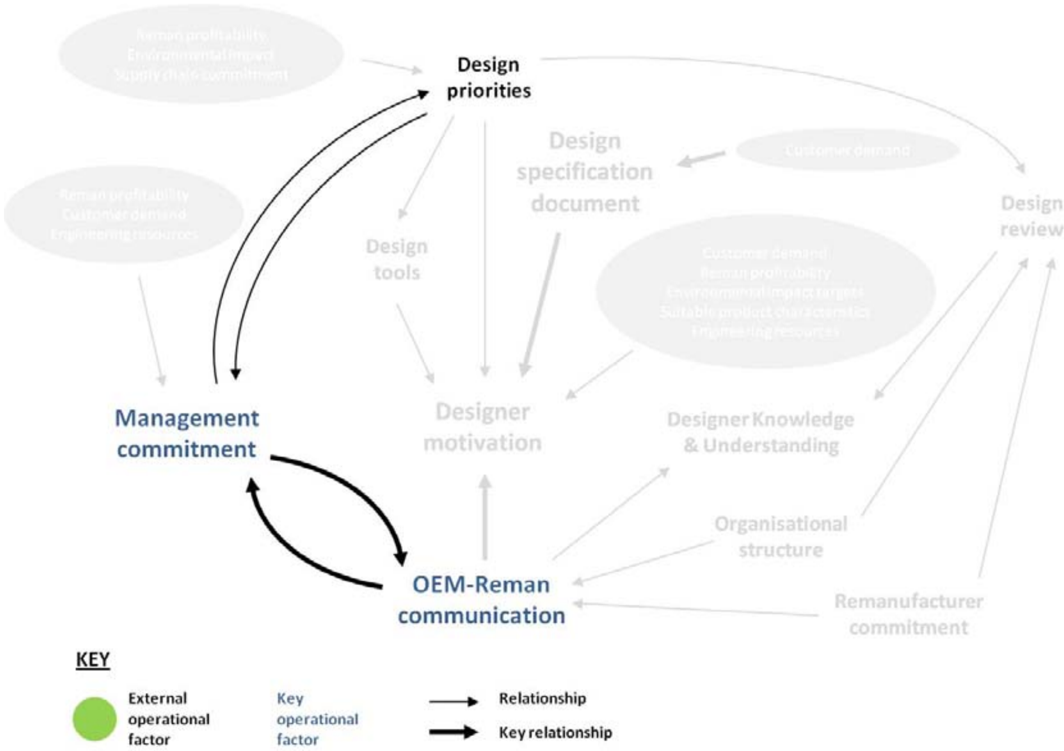


Figure 20: Feedback loops in the network model.

5.4 Validating the Model

5.4.1 Validation philosophy

Following data collection at the three case study companies, case study reports were sent for review by key correspondents to ensure all facts gathered were accurate and representative of their respective companies. This review process ensured the reliability of the case study findings, and enabled the final definition of the external and internal operational factors, and the relationships between them. Following this, the integration network model was developed, which represents the researcher's *interpretation* of the three cases study findings combined.

According to Barlas (1996), model validation is about 'establishing confidence in the usefulness of a model with respect to its purpose'. In this research, model validation was about ensuring the model held three key characteristics:

- Sufficiency: the model represents DfRem integration accurately.
- Clarity: the intended audience will find the model easy to comprehend.
- Appropriateness: the model is presented in a usable format.

Following the development of a first draft of the integration model, two 'validating panels' were invited to evaluate it. One panel comprised of staff from Company A (a case study company), another of staff from a non-case study company from the mechanical / electromechanical sector (Company D). The model was also presented to academics with relevant expertise for further feedback. Of the three case study companies, Company A was selected for validation as its employees had the most experience of DfRem integration, and were therefore able to provide a richer insight into the accurateness of the model. The employees were also considered knowledgeable and experienced enough to best determine the usefulness of the model.

The second validation company (Company D) were selected for similar reasons. Company D is a global OEM of automotive products, with large maintenance and remanufacturing facilities in the UK which employ 190 staff. The company has been active in the UK since the 1970s and has fostered close ties between its remanufacturing management and design engineering team in Germany, with a regular exchange of staff to form cross-disciplinary teams. This practice enables design engineering to assist in the development of remanufacturing processes, and remanufacturing engineers to provide knowledge gained through product take-back for new product development. Therefore, although the UK remanufacturing management invited to participate in the validation panel did not come from an engineering design background, they had a good awareness of the company's design engineering practices from a remanufacturing perspective. This enabled the model to be validated from both the designer (Company A) and remanufacturer perspective (Company D).

Valuable feedback on the identified operational factors and integration network model was also gained through the course of peer-reviewed journal papers that presented the key outcomes of the research (Hatcher et al., 2013b). Further feedback was also sought from academics from the fields of sustainable manufacture and operation management, which led to further improvements to the model's terminology and presentation.

The development of this model— its format and the philosophy underpinning it— was inspired by 'soft systems methodology' (Checkland, 1981). According to Checkland (1995), the absolute validity of a soft systems model is irrelevant or at least unnecessary because these models are not intended to represent 'reality', but instead a stakeholder's viewpoint. Indeed, in a soft systems model some inaccuracies and assumptions may be necessary to make the model more efficient (Hillston, 2003). Therefore, the validation of these models should be concerned with whether the model is relevant, and completely built. However, soft systems practitioners have also been criticised in the past for ignoring the issue of model validity (Barlas, 1996).

Roy and Mohapatra (2003) state that the difficulties in determining causal linkages in soft systems makes model validation a difficult task, even when the model is based upon empirical research. Coyle and Exelby (2000) also state that there is no such thing as absolute validity for these models, only a degree of confidence in their accuracy and usefulness. Indeed, the DfRem integration model is not intended to represent a 'reality' in which all factors and relationships have a causal effect in all organisations, something which posed challenges in developing the validation review format. As a result, validation was conducted in a largely qualitative, subjective manner. This was a logical direction to take: according to Barlas and Carpenter (1990) the validation of such models cannot be entirely objective, formal and quantitative.

Despite these challenges, a review format was devised which would help determine whether the model met the three criteria stated above, and to identify potential improvements which could be made to the final, presented version. When developing a model, it is possible that the researcher will express relationships which are intuitive to them but unclear to others, because intermediate or additional factors are missing. In other words, the model may be insufficient. Having the model evaluated and critiqued by a panel of outsiders (with relevant experience or expertise) can therefore enable these omissions to be identified, improving the overall quality of the model. A panel of outsiders can also determine the clarity of the model by acting as representatives for the intended audience (if the validation panel cannot understand the model, then it can be assumed that the intended audience will also struggle).

5.4.2 Validation protocol

The DfRem integration network model was validated with the assistance of two review panels and academics with relevant expertise. The panel at Company A consisted of five members of staff representing design management, aftermarket management and remanufacturing management, i.e. the three management roles interviewed during the case study research. It was decided that managers would be the best validation panellists as these would be the people with the most knowledge and experience to adequately assess the model. Furthermore, managers are the intended audience for the model, being the individuals with the most control over DfRem decision-making at an operational level. Some Company A staff on the panel had been involved in the case study research and were familiar with its aims and objectives, others were not interviewed for the study and brought a fresh perspective to the DfRem integration issues addressed in this research. The panel at Company D consisted of six members of staff representing remanufacturing production management, quality control and business development.

Models were reviewed by each panel separately due to timing and coordination restrictions, however each review was conducted in the same format:

1. The purpose and content of the validation meeting was presented to the panel.
2. The panel was reminded / introduced to the PhD research background, aims and objectives.
3. Each panellist was handed three sheets of paper: two questionnaires (discussed below) and a printed image of the model for reference / annotation. Panellists were asked to begin taking notes and answering questionnaire questions during the following talk.

4. The external and internal factors were then presented to the panel, followed by an introduction to the model: the relationships illustrated and how the model can be read and understood. Panellists could interrupt at any time if there was something they did not understand, which was important for identifying areas where the model required improved clarity.
5. The panel was then asked to complete the two questionnaires individually.
6. Finally a group discussion on the model and questionnaire answers enabled the panel to arrive at a consensus over what aspects of the model were missing or could be improved, and how the model could be made useful in the future.

As mentioned above, two questionnaires were handed to the panels. The first was a Likert-scale style questionnaire which asked panellists to state their level of agreement with a series of general statements about the model. This questionnaire was used to gauge the general impression of the model’s sufficiency, clarity and appropriateness, and included both positive and negative statements, rephrased in different ways, to help prevent insincere responses. The second questionnaire required the panel to specify in detail any aspects of the model they found unclear, any omissions from the model they had identified, and any suggestions for how the model would be presented and accessed.

5.4.3 Validation outcomes

Following the two validation panels and consultation with academic experts, several improvements were made to the model’s content and presentation. The key issues raised during validation are outlined in Table 11, with the resultant actions taken (if any) described. The modified version of the DfRem Integration Network Model is presented in Figure 21.

The Company A panel was able to provide the most in-depth feedback, partly because several participants had been involved in data collection but also because this company had the most interest in DfRem integration, having already made significant steps towards it. The panellists felt that the model contained useful information, and were able to recognise from the model where the company had already made significant steps and where improvements could be made (namely communication and designer motivation). There was strong agreement that people factors had a significant influence upon DfRem integration. The panel agreed that DfRem inclusion in the PDS was an important factor, although arguably one of the simplest steps to take (implementation is where the real challenges arise). They also agreed that communication between design engineering and remanufacturing was crucial.

They discussed the importance of creating a ‘seamless journey’ from plan to brief to delivery of remanufacturable products. The panel were also keen to emphasise that what may be considered highly important factors for Company A may differ in other companies or markets.

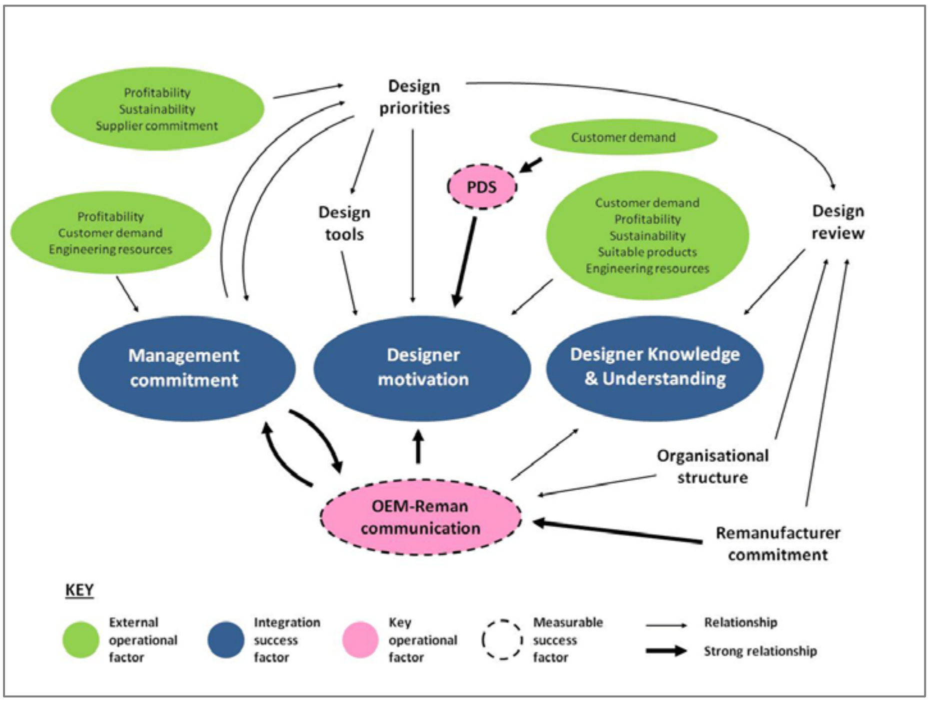
The model was then presented to Company D, following which further amendments were determined. Coming from a remanufacturing perspective, panellists at Company D were not always able to comment on some of the factors regarding the design process, and felt that this kind of information would be of greater value to engineering managers than remanufacturing management. The panel were keen to emphasise their opinion that viewing DfRem as a distinct, specialist task was unnecessary. They felt that many of the technical DfRem issues for their particular products were already addressed by design for manufacture, assembly and service. So, it could be said that the Company D panel did not see the need for distinct DfRem integration at all, however this could be considered a reinforcement of the finding that remanufacturer commitment is an integration factor. The panel agreed that operational factors were more important than technical factors when attempting to enhance the remanufacturing process. They agreed that communication between the two parties was particularly important for a shared understanding, even if this information was more focused upon design information that remanufacturing information. There was also agreement that management commitment and design priorities were significant barriers to DfRem / design for service at Company D.

Table 11: Key model validation outcomes.

Issue raised	Comments	Company / Academic	Action Taken
Model Content (suggested omissions)	The relationship between customer demand and PDS is not as clear-cut, it is predicted customer demand for a product yet to be launched on the market.	A	Explanation provided regarding this relationship would be clarified.
	PDS, communication, and their relationships should be emphasised as they weigh more	A	These factors and relationships have been highlighted to draw

	heavily than other internal factors.		greater attention to them.
	No mention of core return systems.	A	This issue was considered outwith the scope of the model.
	Product size and cost are significant external factors.	A, D	This issue falls within 'suitable product portfolio'. Terminology and explanation was improved.
	Cost is as big an issue as profitability.	A, D	Terminology was improved to better reflect this issue.
	Emissions legislation poses challenges.	A	This issue falls within 'design priorities'.
	Remanufacturing capability.	A	This issue partly falls within 'designer knowledge', and reflects the scepticism which can influence designer motivation.
	Customers designs as well as suppliers can be pose remanufacturing challenges.	D	Terminology was improved to reflect the fact that not all OEMs will be at the end of the supply chain.
	'Measurable factors' is untested.	PB	Remove this element of the model.
	'Customer' in customer demand must be clearly defined.	PB	Explanation of this factor was improved.
Model presentation	The model currently requires verbal explanation.	A, D	Access method will include access to further information if desired.

	The model is intimidating at first glance, don’t know where to start.	D	The model should be available in a digital, interactive format that guides the user through it.
	Meaning behind ‘success factors’ unclear / unproven.	A, PB	This element was removed from the model, although the importance of people factors was still emphasised.
	PDS acronym is unclear, not always referred to as this.	A	Acronym removed.



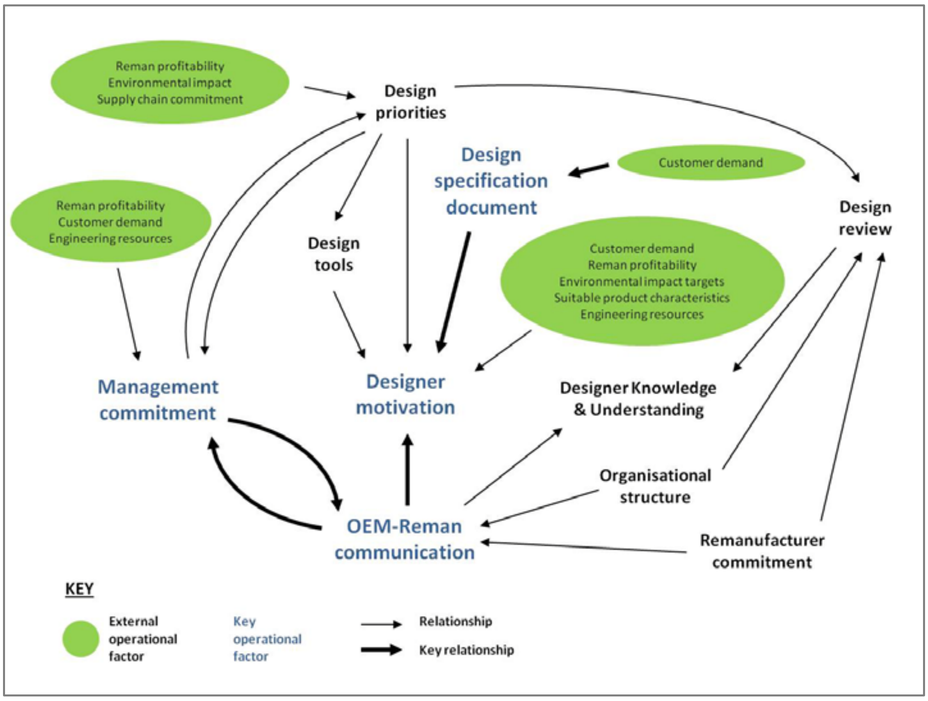


Figure 21: The DfRem integration network model pre and post validation.

5.4.4 Reflection on model validity

Significant improvements were made to the model as a result of the validation process. As outlined in Section 5.4.1, the purpose of this validation was to ensure the sufficiency, clarity and appropriateness of the model.

Sufficiency refers to the accuracy of the results. Accuracy of the information presented in the model was improved firstly through the use of case study reports, and secondly through the approval of academics and practitioners during the validation process. However, it should be noted that the model is based upon information from three case studies, and therefore may not represent all operational factors and relationships that exist in DfRem integration across industry. If there was insufficient evidence gathered during case study visits, a factor or relationship was not included in the model, yet this does not mean that it can never be relevant.

Clarity refers to how simple the model is to comprehend by its intended audience, and appropriateness refers to the usability of its format. The model can be considered clear and appropriate for an academic audience: academics from the validation process, as well as peer reviewers of journal publications from this research, understood the layout and the purpose of the model. A network model is an appropriate way to present operational factors as it has been used to effect in previous literature of a similar nature, for example (Brown and Eisenhardt, 1995).

The model was less clear to the practitioners who participated in validation. They required greater explanation of what each operational factor meant, and were less accustomed to receiving information in the form of a network model. There were concerns that the amount of information contained within the model could be overwhelming, which led to the development of three ‘key practical recommendations’ for practitioners, as outlined in Section 7.1.2. Practitioners involved in model validation also expressed a preference for the model to be available in a digital format with layered information, to improve its clarity and accessibility. The proposed method for model access is outlined in the following section.

5.5 Accessing the model

The feedback from the two validation panels also helped to direct the decision regarding how the model should best be presented to and accessed by its intended audience. The resounding feedback from both validation panels was that the model on its own did not provide enough explanation of what each factor meant. The model at first glance is overwhelming, leaving the reader unclear on where to start. Although it was important that the model did not prescribe a DfRem 'route to success', as this was not considered a helpful interpretation of the research findings, it was decided that the access method should present the information is a step by step way that enabled the reader to follow the model at a comfortable pace.

It was therefore decided that the model could not be presented to industry in a restrictive paper format, instead it must be accessible in a digital and therefore layered and interactive format. The two validation panels agreed that digital access would be preferable, and suggested the model be presented as a web or intranet-based tool or simple animation. This feedback collates with findings in (Lofthouse, 2006) which found that designers prefer visual tools that provide small 'nuggets' of information.

It was envisaged that a digital version of the model would be navigated in the following way (see Figure 22 for an illustration):

1. As the user hovers a mouse over the model, the external factors, internal factors and relationships are highlighted individually.

2. The user will click on the feature they wish to investigate further.

3. Plus (+) signs will appear over each factor or relationship.

4. The user clicks to receive additional information about that particular factor or relationship.

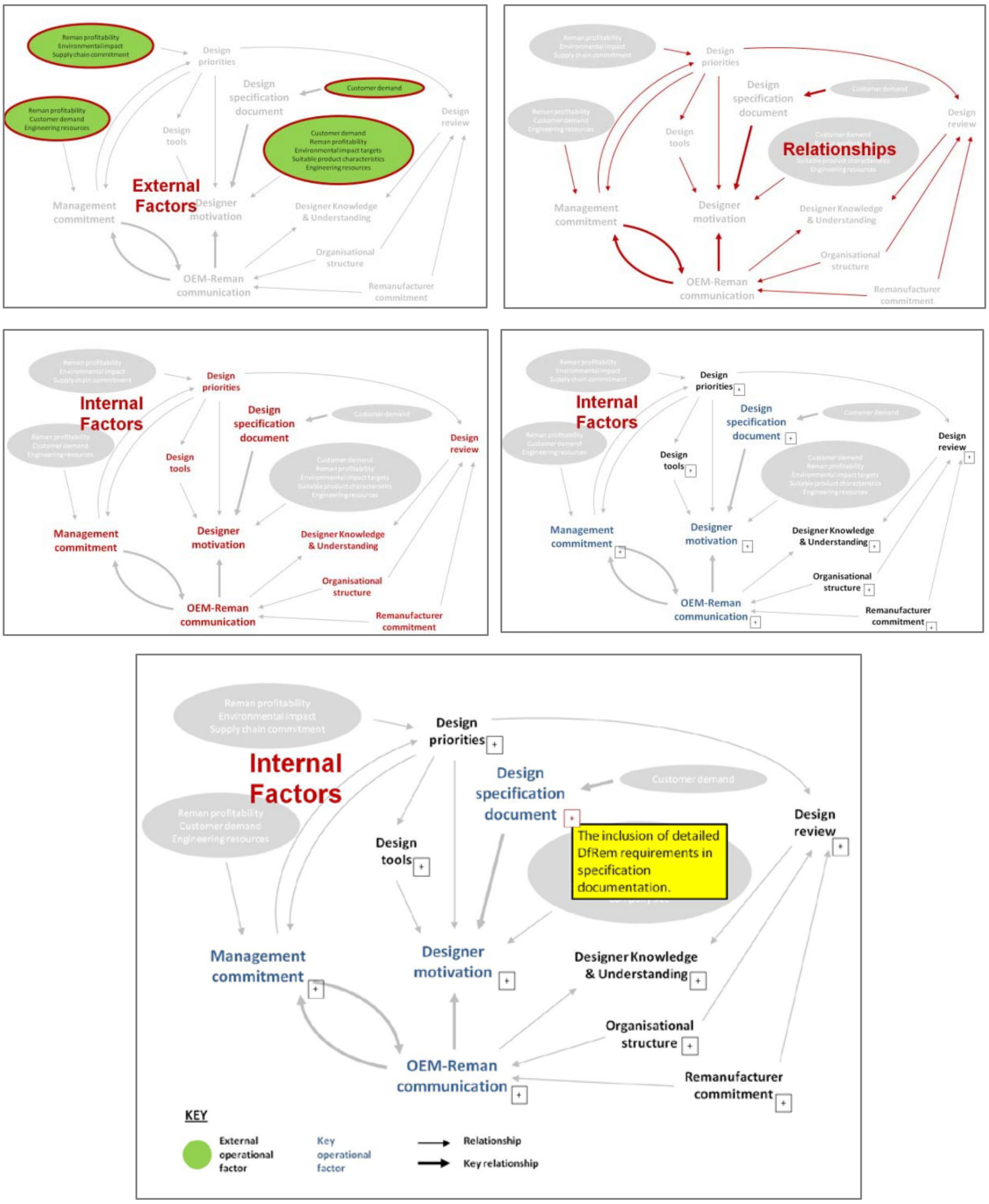


Figure 22: Illustration of the interactive process of using the model in a digital format.

Chapter 6: Discussion

This chapter will discuss the significance and implications of the research findings, and subsequent integration network model.

6.1. Research Results Discussion

At the early stages of the research, the four key research objectives were outlined as follows:

1. Determine the external operational factors which influence the decision to design for remanufacture.
2. Determine the internal operational factors which influence DfRem integration into the design process.
3. Determine and map the relationships between the operational factors.
4. Present this new knowledge in a way that will contribute towards better DfRem integration, by enhancing its usefulness to an OEM design engineering team.

This section will discuss how these research objectives have been met.

6.1.2 External operational factors

The external operational factors were those factors which were found to have an influence upon the decision to integrate DfRem, yet were outwith the control of the case study unit of analysis / practitioner, i.e. design engineering departments or teams working within an OEM organisation. The external factors identified were outwith their control either because they are macro-environmental factors, or factors at the discrepancy of higher levels of management than those operating at a design engineering level. The six external DfRem operational factors identified were as follows:

- Customer demand
- Profitability
- Suitable product portfolio
- Environmental impact
- Engineering resources
- Supplier commitment

These external factors were included in the DfRem integration network model. One of the main elements of model validity is ‘operational validity’, the ability of the practitioner to have control over the factors and the ability to manipulate them (Thomas and Tymon Jr, 1982). Although engineering managers would not typically have control over factors such as customer demand or engineering resources, the identification of these factors and their inclusion in the model provides a more comprehensive understanding of what DfRem integration really means, in particular the potential limitations and barriers to integration. The external factors provide context to the rest of the study of integration factors, and are important to consider during decision-making. For example, there is less value in encouraging an engineering team to invest time and money in formal communication channels with remanufacturing, if in reality the company lacks the resources to be able to carry out this communication regularly and effectively. On the other hand, understanding of the external factors influencing DfRem integration can also have a positive effect on internal operational factors, as illustrated in the network model. Design managers who have a richer understanding of factors such as customer demand, or environmental impact, may be more committed to integrating DfRem issues. Therefore, having these external factors present in the model not only provides a more holistic view of a company’s situation, it may also act as a ‘prompter’ to design engineering teams to become more aware of the relevant facts surrounding remanufacturing in their company. Many of the case study interviewees were lacking in this awareness.

Considering the external factors identified, probably the most predictable inclusion is ‘suitable product portfolio’. This research was limited to case study companies from the mechanical / electromechanical industry sector, therefore products typically fall into this category. Therefore the fact that all three case study companies were interested in remanufacture and DfRem is not surprising, as the companies were all aware that their products were ‘ideal candidates’. This research did not explore what the opposite scenario would mean for DfRem integration— product portfolios which were not naturally suited to remanufacture, such as electronics and plastics products. However, research discussed in Hatcher et al. (2013a) provides some inclination that DfRem is a far less attractive proposition for companies operating in less ‘remanufacturable’ sectors.

It is important to note that the listed ‘external operational factors’ refer to factors which influence the decision to integrate *DfRem* specifically, not the decision to set up a *remanufacturing process*. Although it is theoretically possible that a company would design for remanufacture in anticipation of future remanufacturing activity, the general assumption during discussion of this research is that a company that decides to integrate DfRem has already previously decided to remanufacture its products. Evidence from the case study data reinforced this assumption: although design management at Company C agreed that the company's products were highly suited to remanufacturing, DfRem was not considered relevant as long as no remanufacturing was actually taking place. The external factors driving DfRem are often related to those driving remanufacture. For example, a company may choose to remanufacture because it is known to be a profitable business strategy (Guide, 2000), and it is the fact that remanufacture *is* profitable that drives DfRem: remanufacture is considered more important, and the drive to further increase profits exists. However, it is important that a distinction is made between DfRem external operational factors and remanufacture external operational factors.

One rather surprising omission from the list of external operational factors was 'legislation'. The designers at all three cases study companies did have to consider legislative issues that affected their designs, however there is currently no legislation in the UK which would incentivise the case study designers to design for remanufacture. This is in stark contrast to much of the remanufacturing literature, which emphasises the significance of environmental legislation on companies' move towards increased remanufacturing, and presumably therefore DfRem (Guide et al., 2003, Ijomah, 2010, Lindahl et al., 2006, Parker, 2010); with the exception of Seitz (2007) who found that remanufacturing at automotive case study companies did not help those companies meet environmental legislation. This finding was despite the fact that the industries in which the three case study companies operated— off road equipment and pumps— were identified as high value and growth potential remanufacturing industry sectors in the UK (Chapman et al., 2009).

With the exception of perhaps 'suitable product portfolio', the nature of a company's external operational factors is quite likely to change over time. Customer demands change, environmental issues are becoming increasingly important and the size of a company can expand or contract. It is therefore important that a company does not view the external operational factors as a one-off diagnostic tool but rather a continual reference resource.

6.1.3 Internal operational factors

Identifying the internal factors was arguably the central part of this research. The internal operational factors not only influence DfRem integration, but are factors within the scope, control and influence of the intended audience for this research: design engineering departments and teams (or in some instances immediate stakeholders). The ten internal operational factors for which evidence was found in the case study research were as follows:

- People factors
    - Management commitment
    - Designer motivation
    - Designer knowledge and understanding
- Business factors
    - Organisational structure
    - Design priorities
- Design process factors
    - Design reviews
    - PDS
    - Design tools
- Remanufacturer relationship factors
    - OEM-remanufacturer communication
    - Remanufacturer commitment

These factors were confirmed through the cross-case analysis and 'shaping hypotheses' processes, and represent a list that was refined from a larger number of potential operational factors noted during case study visits. However, not every factor was present (or present to the same degree) at every case study company. This was to be expected because the theoretical sampling used in selecting the case companies meant that cases were selected to represent different stages of DfRem integration maturity. For example, factors such as 'remanufacturer relationship' factors were not relevant at Company C, which has no remanufacturing operations; and less evidence was found at Company A that 'designer knowledge…' is an important factor because designers interviewed were beyond the initial 'basic information' requirements.

The presence or absence of certain factors at certain case companies begins to provide an indication of which factors are most significant, and how 'DfRem integration maturity' could be measured in the future. For example 'designer knowledge and understanding' is an earlier maturity indicator, because it was only Company C designers who called for more basic knowledge on the remanufacturing process and DfRem guidelines. Designers at both Companies A and B felt they had sufficient basic knowledge and could learn DfRem through their own intuition and experience. This suggests that knowledge and understanding is one of the base benchmarks for DfRem integration. On the other hand, only interviewees at Company A had any experience of DfRem in design tools, and even then this experience was limited with possible room for improvement (if the amount of research carried out into this area is to be believed). This would suggest that 'design tools' is a high-maturity factor, not essential for the early stages of integration, but increasingly important as maximum DfRem success is sought.

It is also important to note that the internal operational factors do not appear to be of equal weight. The significance of each factor on a company design process will most likely vary from company to company for a variety of reasons, including integration maturity. Evidence gathered from the three case study companies strongly suggested that the PDS and OEM-remanufacturer communication are highly significant and crucial factors, whereas internal factors such as organisational structure or design tools were identified as noteworthy factors, yet less prominent in the route to better DfRem integration. 'PDS' was considered a particularly significant factor because it was only Company A that had DfRem requirements specified in this document, and designers at both Companies B and C said the main reason for not doing DfRem was simply because it was not required of them. The PDS is how designers may be requested to consider remanufacturing issues during the design process. Similarly, OEM-remanufacturer communication was highlighted as significant again because Company A was the only case study company to have regular, formal communication between the two parties, with evidence that this contributed to the companies' enhanced DfRem integration maturity. Just as decisive was the fact that both Companies A and B cited communication as an area for improvement that would enhance DfRem integration. Furthermore, findings from all three case study companies strongly suggested that knowledge and understanding of current remanufacturing processes and capabilities was important, and as the network model shows this is influenced by OEM-remanufacturer communication.

Another internal factor which could be labelled as 'high opportunity' is 'design reviews'. Although it was only Company A that formally considered DfRem during design reviews (and insufficiently, according to some interviewees), all three case study companies were able to envisage DfRem considerations being integrated into existing design review auditing. The research findings would suggest that inclusions in design reviews is a more effective practical step than the integration of DfRem-specific design tools, which is so often the focus in DfRem literature. The research findings would suggest that this approach would be more widely accepted by designers and managers.

At the early stages of the research, ‘internal factors’ were defined as ‘directly relevant to the design engineering department / team of an OEM (or other immediate stakeholders), and are therefore within an engineering manager’s control’. Reflecting upon the internal factors that have been included in the network model, it is clear that some factors are less within the control of DfRem stakeholders than others. Namely organisational structure and company design priorities are difficult for a manager at a design engineering level to have major influence upon: decisions regarding these factors are most likely to come from top strategic management. These factors could be described as macro-internal: they are directly related to the organisation and relevant to design engineering, yet are factors a design manager must be aware of when considering DfRem integration, and work around rather than directly control. Therefore, it was considered of value to include these factors in the network model.

The development of the integration network model also highlighted the people factors as highly significant, and therefore worthy of emphasis. However, to reiterate, the importance of internal factors will vary from company to company, and from different stages in DfRem integration. Therefore, it was decided that a clear ‘roadmap’ for DfRem would be inappropriate. Instead, the identification of the internal factors may provide managers at any stage of DfRem integration with a ‘portfolio’ of ideas, or actions, or decisions which can be undertaken to improve DfRem integration, based upon what is appropriate for the particular company at that particular time.

At this stage in the thesis it is fitting to look back to the priori constructs which were identified during the ‘getting started’ phase of the research. These priori constructs, inspired by ecodesign success factors identified by Johansson (2002) influenced the direction in which semi-structured interviews were steered. These constructs were taken from ecodesign research, so a comparison with the internal factors influencing DfRem should provide a good indication of some of the differences between the two subject areas. A comparison of the priori constructs and identified internal factors is outlined in Table 12

As can be seen in the table, the priori constructs match the identified internal DfRem factors fairly closely. In some cases, the priori constructs have been expanded upon, in the cases of ‘remanufacturer relationships’ (a priori construct that was not taken directly from Johansson’s list) and ‘the development process’. The research has explored in further detail what specifically about these factors is relevant to DfRem. With the exception of ‘remanufacturer relationships’ (which interestingly was identified as highly significant), all priori constructs were influenced by ecodesign integration research. Therefore, this top-level comparison of the factors influencing ecodesign and the factors influencing DfRem would suggest that DfRem integration is very similar to ecodesign integration. However, as discussed in section 6.2, the differences are revealed when the comparison is examined in more detail.

Table 12: A comparison of the priori constructs and identified DfRem integration factors.

Priori Construct	DfRem internal factor
Management	Management commitment
Customers	[customer demand]- an external factor in this study
[Remanufacturer] / supplier relationships	OEM-remanufacturer communication
	Remanufacturer commitment
	[Supplier relationship] – an external factor in this study
Development process	PDS
	Design reviews
	Design tools
Competence	Designer knowledge and understanding
Motivation	Designer motivation
/	Organisational structure
/	Design priorities

6.1.4 Mapping relationships

It was when the relationships between the operational factors were determined that the usefulness of the findings began to take shape. Understanding how the operational factors influence one another enabled a more representative illustration of DfRem integration to be formed, in the format of a network model. This is something that ecodesign academics do not appear to have attempted, for example both McAloone (2000) and Johansson's (2002) work ends with a simple list of categorised factors. However, reading literature on systems thinking made it clear that for the new knowledge to be genuinely useful, relationships had to be considered.

Some of the identified relationships were more intuitive or predictable than others. For example, it is not new knowledge that customer demand influences the content of a PDS document and it is not surprising that remanufacturer commitment would have an influence upon OEM-remanufacturer communication. Others required a more in-depth understanding of the case study companies to identify. For example, it is interesting to note that designer knowledge is less influenced by training, or textbooks, or academic design tools, and instead was found to be influenced by communication and design reviews. In other words, knowledge and understanding was found to be less about the theory of DfRem as a concept, and more so an open *discussion* about the DfRem issues and challenges facing the particular company at that particular time. It is also significant to note that designers interviewed for this research were less motivated by design tools (or the idea of design tools), and more motivated by the PDS. In other words, being prescribed the task of DfRem and being expected to carry it out as part of their day to day job, rather than the additional help of a design tool that would assign DfRem as a specialist task. Yet, so much DfRem literature focuses upon design tools, and so little on how DfRem principles can be incorporated into a company's essential design objectives.

Based on the initial case study findings and the model validation process, it has become clear that the most significant and relevant relationships exist between management commitment and OEM-remanufacturer communication, design motivation and the PDS document. This knowledge provides design managers with a greater inclination of the best areas for practical action when considering DfRem integration. Understanding the importance of these relationships helps to explain why OEM-remanufacturer communication and the PDS are recommended as the key operational factors that should be focused upon in most cases.

Whether a relationship between two or more factors is surprising or not, it is of significant benefit to be able to identify all these relationships as one inter-connected network and share them with industry. In industry— and life in general – relationships are all around, but a design manager may not notice or consider these relationships. Considering operational factors in isolation of one another is of limited value, as has been discussed in this thesis.

6.1.5 Making the new knowledge useful

The fourth and final objective of this research was essentially the desire to encapsulate the new knowledge in a way that could be genuinely useful to academia and most crucially to practitioners. The benefits of the research outcomes as a whole to both these groups will be discussed in Sections 7.1. The design of the model was inspired by systems thinking literature and Design Research Methodology, and uses text, arrows, colour-coding and bold lines to communicate the various pieces of information generated through this research as one, holistic illustration.

At this stage in the research, not only was it important to ensure that the new knowledge was validated and useful, the way it would be communicated also became an important issue. Once the external and internal operational factors and their relationships had been established, a suitable visual representation had to be developed to ensure that the new knowledge would reach beyond those willing to read a lengthy thesis. The following model design considerations help ensure that the new knowledge is accessible and useful:

- The model can be contained within a relatively small space. As DfRem is a low-priority issue, it was important that the model did not appear overly complex or time-consuming to read and understand. Furthermore, a smaller, simpler model is ideal for printing and distributing in paper format and digitally.
- The model acts as a reference tool, and does not require any input of data in order to communicate relevant information. Again, this was important because DfRem is a low-priority issue. Also, if companies are at the earliest stages of DfRem integration, data may not be available.
- Colour-coding not only makes the model more visually inviting, it communicates valuable information beyond a simple listing of factors and relationships, enriching the information provided without the need for additional text. In general, designers prefer tools and references which are highly visual with minimal use of text (Lofthouse, 2005).
- Similarly, highlighting significant relationships in bold adds an additional layer of complexity to the model without making it unnecessarily more complex to understand.

However, a possible drawback to this approach is the inevitable requirement for additional background information. From looking at the model, it may not be immediately clear to all what is meant by ‘design priorities’ or ‘designer motivation’ and so on, or what the presented relationships between the factors actually mean. This was an issue raised during model validation. Therefore, the model must be accompanied with additional information for those new to the concept or unfamiliar with particular terms or issues. This is why it was decided that the model should be accessed in a digital, interactive, layered format.

6.2. Enfolding Literature

According to Eisenhardt's (1989) methodology for building theory from case study research, 'shaping hypotheses' is followed by 'enfolding literature'; a comparison of the research findings with similar and conflicting literature. A comparison with the conflicting literature is a way to build internal validity, and a comparison with the similar literature can sharpen generalizability. This exercise is a way to improve construct definitions. If the findings from this research are in conflict with the findings of other researchers, it is important that reasons can be given for this anomaly, otherwise it may be assumed that the research findings are incorrect. Eisenhardt says that comparison with similar literature is also important because 'it ties together similarities in phenomena not normally associated with one another'.

As discussed in previous chapters, there is little discussion to be found in the literature on the operational factors that have an influence upon DfRem integration. Therefore, literature exploring operational factors that influence ecodesign integration have been used as a framework for this research. Ecodesign and DfRem are similar concepts with some similar technical factors and objectives, and it was therefore considered useful to look to ecodesign research for an early insight and indication of the kind of factors which may be relevant to DfRem integration (i.e. the priori constructs). However, until this research had been conducted, it could not be assumed that the operational factors that influence ecodesign could be considered inter-changeable with the operational factors concerning DfRem. Once the research data had been analysed and hypotheses' shaped, it was possible to look back to the original ecodesign literature which provided the early framework and determine to what extent the operational factors influencing DfRem integration compare to those influencing ecodesign integration. And of course, it was important to also compare the research findings to any relevant remanufacturing literature which has been published in recent years, to help determine the extent to which this research has furthered knowledge in the field.

6.2.1 Ecodesign integration factors v DfRem integration factors

There were a number of papers covering the topic of ecodesign integration factors which both influenced the early stages of the research and provided a framework from which case study topics and themes were developed. The most influential papers from the literature review were:

- Johansson (2002). *Success factors for integration of ecodesign in product development. A review of state of the art.*

- Boks (2006). *The soft side of ecodesign.*
- McAloone (2000). *Industrial applications of environmentally conscious design.*
- Lindahl (2006). *Engineering designers' experience of design for environment methods and tools* **-** *Requirement definitions from an interview study.*

In the following sections these papers are compared and contrasted with the findings from this research.

People factors

Boks (2006) 'The Soft Side of Ecodesign' focuses upon the socio-psychological operational factors which influence ecodesign integration, and Johansson (2002) compiles a list of success factors for ecodesign integration based on an extensive literature review. In both these papers, management commitment and support for ecodesign was highlighted as a key factor, which matches the findings for DfRem integration.

McAloone (2000) explores top management commitment specifically, and found that whilst this factor was important at the early stages of integration (to help 'kick-start' the process), middle management commitment is more significant for ecodesign integration in the long-term, as these managers work more closely with the design team. These findings correspond with DfRem integration: middle managers at Company C expressed the need for top management commitment before DfRem integration could seriously be considered, whilst designers at Company A did not express any concerns regarding management commitment, because it was generally understood that design managers were in favour of DfRem.

Johansson (2002) stated the importance of training and education for designers in ecodesign integration. Whilst this subject was not explored extensively in this research, the interview data would suggest that both managers and designers did not feel that additional training was required, and that a basic engineering education was sufficient in allowing designers to pick up the concept of DfRem fairly quickly. Designers interviewed stated a preference for learning through both their own experience and the experience of others around them. Perhaps this contrast indicates a further difference between DfRem and ecodesign: the principles and logic behind DfRem are much more closely aligned with traditional engineering design: for example Boothroyd and Dewhurst's DfMA guidelines. Ecodesign, on the other hand, is renowned for requiring specialist knowledge and specific data. This is a particularly common criticism of ‘lifecycle analysis’ (McAloone, 2000; Lindahl, 2006). However, McAloone (2000) also states that some ecodesign tasks only require ‘common sense’ from a conventionally educated designer.

Considering designer knowledge and understanding further, this research was more in line with the findings of Lindahl (2006) in his study of engineering designers’ experiences of ecodesign tool integration. This paper highlighted the importance of being able to transfer ecodesign knowledge from older, more experienced designers to newer ones. Designers interviewed at Company A stated that this was how they had learned about DfRem guidelines, and felt this has been a sufficient education in itself. Designers at Companies B and C also felt DfRem was something they could quite easily ‘pick up’ on the job. However, Lindahl’s concludes that ecodesign tools would be a way of transferring this knowledge from one level of experience to another. Whilst some evidence was found that design tools could assist in the sharing of DfRem knowledge— mainly Company A’s DfRem guidelines booklet— in general it has been concluded that DfRem tools are not an optimum solution to the problem (managers at Company A admitted that these guidelines are rarely referred to).

Designer motivation was a factor that emerged strongly from the research findings. In his summary of ecodesign success factors, Johansson (2002) refers to motivation as ‘a new mindset emphasising the importance of environmental considerations’. This ‘new mindset’ ties in with the findings that designer motivation is linked to their awareness of the external factors surrounding remanufacture and DfRem: customer demand, profitability, the need to reduce environmental impact. Designers thinking in these terms were more motivated to carry out DfRem. Johansson also links motivation to ‘being encouraged to take an active part in the integration of ecodesign’. Designers interviewed at both Company B and C stated that they were not motivated to do DfRem simply because they were never *expected* to do it.

Another element of designer motivation cited by both Johansson (2002) and McAloone (2000) is the presence of an ‘environmental champion’. Although this research did not arrive at any solid conclusions regarding ‘remanufacturing champions’ (only Company A Location 3 had a distinct remanufacturing liaison, while Location 1 had integrated DfRem without one), designers at Location 3 cited the remanufacturing liaison as one of their main motivators. A difference between the recommended ‘environmental champion’ and the remanufacturing liaison is the faculty with which they motivate designers. Environmental champions are intended to have specialist knowledge in environmental legislation compliance, material properties, LCA data etc; whereas Company A’s remanufacturing liaison provides more of a communication and feedback function between the designers and remanufacturing management. Perhaps this difference is linked to the fact that designers interviewed at Companies A and B (and to a lesser extent Company C) did not feel that DfRem requires highly specialist knowledge and skills.

McAloone (2000) also suggests that designer motivation can be enhanced by providing designers with real-life ecodesign examples, including tours of remanufacturing or recycling facilities. This corresponds with findings from this study: remanufacturers at Company A provided examples of times design managers had been motivated to promote DfRem after facility tours, and design management at Company C expressed an interest in more real-life examples of successful remanufacture and DfRem to help them decide the best course of action.

A striking difference between the findings of this study and that of McAloone (2000) can be seen in McAloone’s finding that after initial reservations had been overcome, designers can personally drive ecodesign integration because they care about environmental issues. This ‘design motivation’ advantage was not evident in the DfRem study, most likely because remanufacturability is more closely linked to company profits than protecting the environment. Whilst designers may wish the company that employs them to remain financially successful, this motivator is less likely to spark an emotional response in individuals.

Business factors

Johansson (2002) identified close supplier relationships as a success factor in ecodesign integration. Similarly some of the case study companies investigated in McAloone (2000) cited supplier relationships as having an impact upon ecodesign integration, because suppliers are a source of ‘untapped information’ regarding material properties etc. This particular advantage was not raised during the study of DfRem integration factors, rather suppliers were viewed as more of a barrier because they would often supply components with poor remanufacturability. McAloone (2000) proposes that companies can provide suppliers with ecodesign specifications, however in reality, aftermarket management at Company A expressed difficulty in convincing suppliers to design for remanufacture.

Considering design priorities, McAloone (2000) observes that for existing products and those which are currently in-manufacture, ecodesign is of a much lower priority. This finding may help explain why DfRem was considered such low priority at all the case study companies, despite the potential benefits. Like many OEMs in the mechanical /

electromechanical sector, the three case study companies were all working with very stable designs which had been developed over years and had been manufactured for a long time. Most product development work at the case study companies involved refining and customising an existing framework for a successful truck, engine or pump design.

Design process factors

Johansson (2002) states that for successful ecodesign integration, environmental considerations must be included as early in the design process as possible. This would concur with the findings from this research that DfRem's presence in the PDS has a strong influence upon DfRem integration. Having DfRem present in the PDS suggests remanufacturing issues are being considered at a pre-spec stage. A study by McAloone et al. (1999) found that companies that were most successful in ecodesign had at least some input at the pre-spec stage. As for the PDS itself, McAloone (2000) expressed similar findings to this research: simply, designers will do ecodesign if they are expected to, because it is specified in the PDS. When designers at Company A were asked 'why' they were willing to design for remanufacture, the simplest answer was that it was in the PDS i.e. part of their job. However, McAloone (2000) states that designers need extra guidance to follow ecodesign specifications, whereas designers at Company A stated that following DfRem specifications was not an unusually difficult or challenging task. Perhaps this difference is because DfRem guidelines have much in common with DfMA guidelines which designers are typically well-versed in, or perhaps the designers interviewed were unable to distinguish what would be considered 'challenging' design and what they are proficient in due to years of experience and practice.

Boks (2006) found that environmental checkpoints, reviews, roadmaps and milestones were important for disseminating ecodesign knowledge to the appropriate persons and therefore the realisation of ecodesign principles in product development. In other words, having clear goals, a formulated integration plan and regular assessment will assist designers in carrying out ecodesign. The three case study companies involved in this research did not express a desire for such increased formality in DfRem— in a way DfRem was viewed as too periphery a concern to merit dedicated milestones etc. This perhaps highlights a key difference between current attitudes to ecodesign and DfRem. Whilst ecodesign is also not a top design priority in most firms, there is a greater sense of 'urgency' in integrating ecodesign, hence the need for milestones and roadmaps. This may be linked to the fact that ecodesign is viewed as being increasingly important as environmental legislation increasingly dictates company activities, as well as a general societal change towards environmental awareness and concern from customers. The same cannot be said of DfRem, at least not in the non-automotive sector covered by this research, where there is currently no legislation driving the decision to design for remanufacture. Of course, this may change in the future if legislation were to drive more remanufacturing activity in a wider range of industrial sectors. Some researchers are certainly anticipating waste legislation will become increasingly stringent in the future (Giuntini and Gaudette, 2003, Ijomah, 2009).

However, returning to Boks' (2006) finding that environmental checkpoints, milestones, reviews and roadmaps are important for ecodesign integration; although formal planning of DfRem did not emerge as a popular option, the opportunities from regular reviews was something that all three case study companies agreed upon. Interviewees from various roles within the three companies recognised that including DfRem concerns in regular design reviews could motivate designers and bring the remanufacturer's concerns forward in a more formalised manner. However, this finding is in slight contradiction with the findings of Lindahl (2006), in a study of designers' experiences with ecodesign methods and tools. In this study designers stated a dislike for methods which involved high levels of collaboration between individuals, due to the additional stress and inconvenience of co-operation and co-ordination involved. Therefore it is possible that while design reviews attended by aftermarket / remanufacturing and design engineering is a good idea on paper, the reality may be more complex than it is worth. Indeed, the remanufacturing liaison at Company A stated that his 'serviceability reviews' were regularly scheduled in too late in the design process for any real design changes to be possible.

Interviewees in the study by Boks (2006) agreed that customised tools tailored to company needs were important for successful ecodesign integration. In contrast, designers and design managers at the case study companies were not particularly interested in customised tools, or in the use of any kind of design methods for DfRem. There could be a few reasons for this difference. Firstly, the designers interviewed at Company A, that currently designs for remanufacture, did not perceive DfRem to be a distinct design activity, rather just one of many design considerations to be included in their day to day work. Therefore specialised DfRem tools seemed unnecessary to them. Furthermore, the introduction of new methods and tools into a company often requires considerable time and resources, and as DfRem does not instil the same sense of 'urgency' or priority as ecodesign, investing time and resources may be perceived as a less attractive proposition to managers.

OEM-remanufacturer relationship factors

In Boks (2006), a lack of cooperation between departments was found to be a key barrier. In this research, the relationship between remanufacturing and design engineering (and aftermarket) was found not just to be a 'barrier', but findings from Company A also indicated that improved communication does indeed make a difference to DfRem awareness and motivation amongst designers. McAloone (2000) emphasizes the advantages an 'environmental champion' can bring to ecodesign integration. A comparable role identified in this study was the 'remanufacturing liaison' at Company A. McAloone states that an environmental champion should enable both horizontal and vertical communication, which was certainly the case for the remanufacturing liaison, who would communicate across to remanufacturing managers and down to design engineers.

Findings from Lindahl's (2006) study of ecodesign tool integration raises some important issues regarding cooperation between the OEM and the remanufacturer. Designers interviewed for Lindahl's research expressed a dislike for ecodesign methods and tools which required high degrees of collaboration, because this of course requires higher degrees of cooperation and coordination which makes the process more difficult and time-consuming. Whilst interviewees at both Companies A and B expressed interest in greater levels of communication and collaboration between design engineering and remanufacturing, it is possible that in reality this ideal would create more negatives than positives.

As a whole, the emergence of 'OEM-remanufacturer relationship' factors as significant in this research highlights yet another key difference between ecodesign and DfRem integration. The ecodesign literature has less to say about these issues because in general ecodesign is not so specifically focused upon the product's end of life, and therefore is not so concerned with relationships with other parties outwith design engineering (although supplier relationships are mentioned). DfRem on the other hand appears to be very much influenced by these relationships.

6.2.2 Comparison with previous DfRem literature

This section will discuss the research findings in relation to other literature on the subject of DfRem. Although the operational factors influencing DfRem integration had not previously been fully addressed by the literature, there are still several interesting comparisons to be made.

The most relevant comparisons could be made with Charter and Gray (2008), an extensive report on the state of the remanufacturing industry and product design, particularly in the UK. First of all, this report highlights the problem that there is often confusion over the definition of ‘remanufacture’, which can create barriers to DfRem. Findings from this research reinforce this view, and the problem was particularly apparent at Company B, where the term ‘remanufacture’ is not typically used, although the company’s aftermarket services match the definition of the process (Ijomah, 2002).

Charter and Gray have also acknowledged that DfRem is unlikely to be of high priority in a company design process, a reality that was expressed time and again by interviewees during this case study research. They also state that to encourage a higher prioritisation, OEMs must have a better awareness of the business case for DfRem, and a problem is that the link between profitability and DfRem is not clearly understood. This would certainly concur with the findings of this research: management at Company B stated that they could not be committed to DfRem without better evidence of its economic benefits to the company, and managers at Company A were not fully aware of the actual profitability of remanufacture for their company as a whole. The report also calls for more case examples of successful DfRem, something both Companies B and C expressed a need for before they could realistically commit to DfRem integration. Considering priorities further, Charter and Gray also acknowledge in their report that DfRem is not always the best compromise overall, and this has to be taken into consideration when proposing increased DfRem activity. This rang true with the case study findings, where both Companies A and C were in situations where design compromises that enabled them to improve the efficiency of their products and meet emissions legislation understandably took precedence over DfRem design features. This is an important message to academics promoting DfRem.

Considering designer motivation, Charter and Gray state that DfRem suffers similar problems to ecodesign: designer ‘apathy and suspicion, and ignorance of potential for profit’. A generalisation, and certainly not true of all designers interviewed for this research, although some evidence was gathered that suggested both designers and engineering managers could be unaware of the potential benefits of DfRem, and sceptical about the quality of remanufactured products. These issues could undermine attempts to integrate DfRem into the design process.

Discussing the lack of DfRem in industry today, Ijomah et al (2007) reference:

'Also, designers may lack remanufacturing knowledge because, being relatively novel in research terms, there is a paucity of remanufacturing knowledge and research (Guide 1999),'

This research has listed designer knowledge and understanding as an operational factor that influences DfRem integration. Designers and managers at Company C expressed a need for more basic knowledge of the remanufacturing process, and lack of understanding of the benefits of remanufacturing as well as scepticism of modern remanufacturing techniques were identified as barriers at both Companies A and B. However, interviewees at Companies A and B explicitly expressed opinions that knowledge was not a major issue, and not one which would be particularly difficult to overcome.

Ijomah et al (2007) also allude to the conflict between DfRem guidelines and environmental legislation, as experienced by both Companies A and C (Tier 4 emissions legislation, namely). The paper highlights the importance that DfRem considers the fact that remanufactured products must comply with modern environmental legislation, and therefore must accommodate this requirement. Findings from this research have suggested that meeting the compromise between remanufacturability and environmental legislation is not a simple task, and in reality it is most likely that DfRem will be compromised when conflicts of interest arise.

Other relevant DfRem papers include Shu and Flowers (1999) and Zwolinski et al. (2006). Both these papers address the fact that DfRem is often viewed and discussed from a 'design for X' perspective, treating DfRem as a specialist design activity. Shu and Flowers (1999) make the point that DfRem guidelines are often in conflict with other DfXs, such as 'design for assembly' and 'design for recycling', and this must be taken into consideration when prescribing any DfRem approach. The findings from this research would certainly concur that a conflict of 'DfXs' is an issue, and not just a technical issue but one that may influence a designer's motivation to invest time and energy into DfRem. The most recurring example found in the case studies for this research was the conflict between design for lower emissions and DfRem. However, the author's conclusions do not so clearly correspond with opinions expressed in Zwolinski et al. (2006): that DfX is an unhelpful way of thinking about DfRem because it assumes designers have adequate knowledge. This is a similar issue to the one raised in Ijomah et.al. (2007), discussed above. Whilst this research did identify that designer knowledge is a fundamental component of DfRem integration, it was not found to be one of the biggest challenges a company will face. Instead the findings from this research would suggest that the ‘DfX mentality’ is unhelpful more so because it assumes that DfRem is both more important (from a management perspective) and more ‘different’, or specialist, than it would seem to be in reality. This research found the issue of management commitment (which is linked to design priorities) to be a more significant factor. It is the author’s conclusion that the DfX view of DfRem has contributed to the (part) myth that DfRem is particularly challenging or knowledge-heavy than other common design concerns, by setting it apart as a distinct design task.

6.3 Research Reflection

This research set out to build theory in the field of DfRem research, specifically to explore the operational factors that influence DfRem integration. As a result, a series of external and internal operational factors have been identified, and an integration network model has been developed that illustrates the relationships between them.

Some of the key challenges in conducting this research included finding case study companies that met all the necessary criteria and were willing to contribute to the research, particularly because DfRem is not a subject that most practitioners are accustomed to discussing in such detail. For this same reason, conducting semi-structured interviews was often a challenge as interviewees did not always immediately understand the purpose of the research, particularly at Companies B and C. However, the designer perspective was a core element of this research and these challenges were overcome with practice and finding new and better ways to communicate the research and interview questions over time. Another particular challenge associated with the qualitative nature of this research was the ability to ascertain evidence (or lack of) for factors and relationships, as all evidence was based upon the views and experiences of individuals, as well as the researcher’s observations. The use of evidence tables acted as a good tool for ‘double checking’, and revealing researcher bias and assumptions that may have otherwise remained unnoticed.

As well as the final deliverable — the integration network model— there were a number of interesting findings and observations that came from this research, which could be of relevance to both academics and practitioners. Firstly, it was interesting to note that none of the three case study companies were driven carry out DfRem in order to meet environmental legislation (such as the ELV Directive), despite most DfRem literature being framed in this context.

Another interesting observation that arose from the research was the nature of DfRem knowledge that design engineers required. Generally designers did not feel that they needed prescribed, explicit knowledge of generic DfRem guidelines. Instead, knowledge and understanding of the company's current remanufacturing process, its capabilities and requirements was considered more valuable. This has implications for the future of DfRem research, in particular the prescription of specialised methods and tools, which may not always be the most effective way to inform designers of how they can make their own products more remanufacturable. The observation also has implications for how practitioners train and educate design staff.

This research has also contributed to creating a distinction between ecodesign and DfRem, as discussed in the previous section. Clearly not all companies remanufacture or design for remanufacture to meet environmental goals, and therefore it should not be assumed that the two research fields are inter-changeable. One of the key differences highlighted in this research was the emphasis upon OEM-remanufacturer communication in DfRem integration, because another party has a stake in the design of the product (alongside the manufacturer, retailer, end user and so on). This research has indicated that communication is an issue that practitioners should pay particular attention to, and is a key area for future DfRem research.

More generally, the process of conducting this research has highlighted the challenges of making assertions and reaching conclusions in organisational research. Companies, design teams and design processes are complex, and it is therefore difficult to make prescribed recommendations to industry as a whole. The individual challenges and barriers faced at the three case study companies (and even different locations in the case of Company A) highlighted this issue. All three companies could be considered 'ideal candidates' for remanufacture and DfRem based upon the characteristics outlined in the literature, but reality has shown that it is not simply a case of 'good' and 'bad' products or services. When DfRem integration should be recommended remains unclear. One possible way to alleviate this problem would be further studies and case examples of the relationship between DfRem and increased profitability, as discussed further in Section 7.3.

Chapter 7: Conclusions

This final chapter will outline the overall research contributions to both academia and industry. The chapter will then go on to discuss the limitations of this research study, and the future research needs which have been identified as a result of these research findings.

7.1 Research Contributions and Beneficiaries

The research aims and objectives were formed from an identified gap in the literature: no papers could be found that explored the operational factors which influence DfRem integration into the design process. However, identifying a knowledge gap is not in itself a sufficient reason to embark upon a research project: the research must have genuine relevance, significance and usefulness to stakeholders, whether these are in academia, industry, the public or a combination. Afterall, a 'knowledge gap' may exist simply because the topic is of no interest or benefit. According to Thomas and Tymon (1982), the practical relevance and usefulness of research outcomes should be assessed with five criteria:

1. Descriptive relevance: the research findings are accurate.
2. Goal relevance: the factors identified in the research correspond with those factors that practitioners wish to influence.
3. Operational validity: the practitioner has control / can take action over the identified factors.
4. Non-obviousness: the theory exceeds the common sense of the practitioner.
5. Timeliness: the theory is available to practitioners at a time it is required.

7.1.1 Contribution to knowledge

The process of conducting and analysing the three case studies for this research has found new knowledge not previously covered by the literature.

- Knowledge of the significance of operational factors upon DfRem integration.
- Knowledge of those external and internal operational factors.
- Knowledge of the relationships between the operational factors.

Academia will benefit from the evidence that operational factors are also significant to DfRem integration, as well as technical factors relating to physical product properties. Most research to date has focused heavily on these technical factors and the subsequent development of DfRem design tools, yet the findings of this research did not find DfRem-specific tools to be of high importance to companies, and knowledge of technical factors was not the main concern. Therefore, the new knowledge of the importance of operational factors will open up debate over where DfRem research should be focused in the future.

Academia will also benefit from the differentiation of DfRem from ecodesign. Academics studying DfRem will now have some DfRem-specific findings on operational factors to refer to, as opposed to making the assumption that ecodesign factors are one and the same. In many of the DfRem papers read for this research, the literature review sections were full of references to ecodesign papers, without making a distinction between the two fields. It is the author's opinion that this practice only adds to the confusion between DfRem and ecodesign, which acts as a barrier to successful DfRem (Charter and Gray, 2008). The new knowledge of external and internal operational factors that influence DfRem integration has demonstrated that while DfRem and ecodesign face similar barriers and challenges, it should not be assumed that findings from the two fields are inter-changeable.

Knowledge of the relationships between operational factors enriches the knowledge of external and internal factors, laying the foundations for more detailed studies in the future with more practical recommendations for DfRem integration.

7.1.2 Contributions to practice

As well as the new knowledge contributing to the DfRem literature and providing benefits to academia, it was important that the research should also provide benefits to practitioners: managers seeking to integrate DfRem into their company's design process, designers expected to design for remanufacture, and remanufacturers affected by the design of their incoming cores.

Considering the three case study companies, that represented three different stages of DfRem integration, the primary 'target audience' for the new knowledge would be a company like Company C, that is at the very earliest stages of DfRem integration, and therefore requires the most guidance, and the most basic advice (a 'starting point' for integration). However it was also important that more advanced companies like A and B could also use the new knowledge to improve their current practice and progress in DfRem integration as they saw suitable.

Practitioners will benefit from some basic guidance on what steps can be taken to ensure remanufacturing issues are considered during the design process. In the past if an engineering manager were to look to the literature for information on DfRem integration, most advice would involve simply the use of DfRem-specific design tools and DfRem guidelines. This new knowledge, and the subsequent development of the network model, provides significant improvements on that advice:

- A 'portfolio' of different measures a company can take to improve overall DfRem integration, from communication channels to design specifications.
- An understanding of the achievable goals of these integration measures, which may lead to more remanufacturable products (motivated and competent design management and designers).
- Understanding of the relationships between the factors enables a company to gauge where they are now, and where they should go in the future to achieve these goals.

Summarising, it is intended that this new knowledge and the DfRem integration network model will assist managers in planning and decision-making that will ultimately lead to products which are better designed for that company's remanufacturing processes. It was not the intention of the research to provide a clear roadmap to better DfRem integration, because every company's experience and capabilities will differ. However, based upon the key factors and relationships that were identified through the research, and feedback and advice from practitioners during model validation, three key practical steps towards better DfRem integration have been outlined:

1. Ensure managers and designers are informed on external factors e.g. the profitability of remanufacturing activity, for example through the use of company newsletters, staff inductions etc.
2. Ensure DfRem is included in design specification documentation, e.g. through the inclusion of a dedicated section.
3. Ensure regular, quality communication between remanufacturers and designers e.g. through an established 'remanufacturing liaison'. Communication should be used specifically to include the remanufacturer's perspective in the design process, for

example a scheduled presence at early design reviews, but also more generally to raise awareness of remanufacturing capabilities and contributions to the overall success of the business.

7.2 Research Limitations

Whilst the research was carried out as thoroughly and comprehensively as possible, there were a number of limitations to the study which must be considered when drawing conclusions and generalisations from the findings.

The ‘external validity’ of case study research is concerned with the degree to which the research findings can be generalised beyond the immediate case study companies (Yin, 2009). Unlike quantitative survey methodologies, when sampling is designed to ensure results can be statistically generalised, case study research strives to generalise the theory which has emerged from the case study findings. To truly determine generalisation, the theory must be tested through replication of the original case studies— that is, testing the theory in similar companies previously uninvolved in the research to ensure similar results are found. Effective replication logic would require each of the three DfRem integration maturity stages to be replicated, as this was a key differentiating factor between the case study companies. Limited time and resources did not permit such replication to take place, although validation was carried out with a company that closely matched Company A i.e. advanced DfRem integration maturity, which went some way towards external validity.

Considering the generalizability across industry sectors, this research has only covered companies working within the mechanical / electromechanical sector, and therefore cannot be generalised across other sectors such as ICT equipment or office furniture. Although similarities between the research findings and ecodesign integration literature (which covers a wider range of industry sectors) may suggest some possible generalisation, there is also evidence to suggest that the operational factors that influence DfRem integration may differ across different sectors. For example, the technical DfRem challenges facing designers of electrical and electronic equipment are quite different from mechanical products (Hatcher et al., 2013a), which may have an effect upon how DfRem is perceived and acted upon within those companies. Even within the mechanical industry sector there may be some smaller differences. For example, none of the case study companies were affected by product end-of-life legislation, whereas the ELV Directive may have an impact upon the external operation factors at an automotive case study company.

7.3 Future Research Needs

Considering both the limitations of this study and the fact operational factors that influence DfRem integration is a largely unexplored research topic, several avenues for future research have been identified at the end of this research.

A measured study of DfRem benefits

At the end of a literature review paper produced through the course of this research (Hatcher et al., 2011), one of the conclusions was that there is a need for more empirical evidence which demonstrates the true benefits of designing for remanufacture:

'There is a need for more case studies and analysis that effectively demonstrate exactly how and to what degree DfRem has an impact on the remanufacturing process and the various stakeholders involved.'

There have been several studies carried out which aim to determine the benefits of remanufacture as an end-of-life solution, however, these studies do not extend to the consideration of whether DfRem is worth a company's additional time, resources and effort.

Reflection upon the case study findings – and the overall experience of the researcher – supported this view and expanded upon it. Not only is there a need for more empirical research into the true benefits of DfRem, but it is the author's view that DfRem researchers should be more questioning in their view that formalised DfRem is always a worthwhile and necessary design activity. A debate is needed regarding which companies, which products and under which circumstances should formalised DfRem be prescribed, and under which circumstances it may be deemed unnecessary.

The thinking behind this view was formulated primarily from experience at Company B, a company that remanufactures its products but does not 'design for remanufacture', at least, not explicitly. Evidence was gathered at this case study which strongly suggested that Company B's pumps are already highly remanufacturable, partly due to the nature of the product and also due to existing 'design for maintenance' principles that were already an intuitive part of the company design process. Although areas for improvement were identified, which were incorporated into the integration network diagram, the general view expressed by interviewees across the different company departments (engineering design, aftermarket and service / remanufacture) was that formalised DfRem was unnecessary for Company B. In this context 'formalised' DfRem refers to explicit actions such as the implementation of DfRem tools, or specific inclusion of DfRem guidelines in the PDS. Interviewees felt that Company B's pumps were already highly remanufacturable, and the researcher was inclined to agree.

This is not to say that Company B should not be considering its products' end-of-life processing, but rather that the view of DfRem as a distinct and prescribed design task is perhaps unsuitable, unhelpful or unnecessary in some company settings.

More detailed study of internal factors

Prior to this study, very little consideration had been given to operational factors in the body of DfRem literature. Therefore, the integration network model which has been developed as a result of this research was painted with a rather broad brush, aiming to cover a broad and holistic range of possible DfRem integration factors, both external and internal. This work has provided an overview of the many factors which may influence DfRem integration, and the model provides some top-level guidance, or steps, that can be taken towards improved integration. However, the specifics of each factor remain unclear.

This work has opened up a great many questions which could be explored in further research, which would improve the robustness of the integration model and enhance the guidance associated with it. Further research is required for many of the identified factors, if not all of them, to better understand their influence upon integration and what practical steps can be taken to lead to more remanufacturable products.

To illustrate this point, take the example of 'OEM-remanufacturer communication'. This particular factor was flagged as highly significant both throughout data collection and model validation. But the detail of this communication is still missing. What kind of communication is most beneficial? When, and between whom? Or, to take another example, product design specifications. The research has indicated that including DfRem considerations in the PDS is a significant factor, but what specific information should be included in the PDS, in which contexts, and how are these decisions made? These questions were outwith the limitations of the research, and could constitute entire research projects in themselves. While this research was highly qualitative and exploratory, further studies into the specific details of DfRem integration could move in a more quantitative direction, something which was not previously possible due to the scarcity of information and understanding in this specific research area.

Further research of external factors

Following on from the discussion of the need for an in-depth study of internal factors, the author believes there could also be value in a more detailed study of the external factors that affect DfRem integration. It was decided from an early stage that this research would focus upon the perspective of the designer, and therefore greater priority was given to the exploration of factors which designers and managers can control, i.e. the internal operational factors. Of course, the research could not ignore the relationships between internal and external factors, and therefore one of the objectives of this research was also to identify external factors which influence DfRem integration.

There has been much discussion in the literature regarding the factors which influence the decision to *remanufacture*. However, less attention has been paid to the factors which influence the decision to *design for remanufacture*- this would be the external factors identified in this research. Whilst there is much crossover between factors, for example 'customer demand' and 'suitable product portfolio', it cannot be assumed that if a company decides to remanufacture, DfRem will automatically follow. The case study of Company B illustrates this point.

Furthermore, the resultant model of this research assumes that designers do not have control over external factors. However, if feedback loops were identified, this assumption would have to be modified.

Therefore, it could be of value to explore the external DfRem factors in greater detail, to determine their relationships and what factors have an influence upon them. For example, it has been suggested that 'customer demand' is linked to customer perceptions of remanufactured products as 'second hand' (Ijomah et al.,2007). Further exploration of these factors would enhance our overall understanding of remanufacture and DfRem further, and perhaps also enhance understanding of the circumstances under which DfRem is appropriate.

Development of a DfRem maturity model

The findings from this research strongly indicate that the prevalence and relevance of internal operational factors is linked to DfRem integration maturity. This was predicted at the early stages of the research, when case study companies were consciously selected to reflect different stages of DfRem integration, which has been referred to as ‘integration maturity’. Because the three case study companies were at different stages of ‘integration maturity’, it was to be expected that not all companies would display evidence of all operational factors. Indeed, evidence of most factors was found at Company A, less at Company B, and very few at Company C, the company with no current remanufacturing or DfRem activity. It is envisaged that the knowledge communicated through the network model would be of most benefit to a company at the earliest stages of DfRem integration. Therefore, the question has to be asked: how would a company like Company C know where to start, and what steps to make towards better DfRem integration? It was the aim that the DfRem integration network model presented in this thesis can assist design managers in determining approximately what level of maturity their company has achieved, and what direction the company should move in to achieve greater DfRem integration. For example, a manager may see from the model that the company has made steps towards better integration because remanufacture is discussed in design reviews and managers are generally committed to the cause, but can see that the design team’s communication with remanufacture is lacking.

The association between operational factors and maturity is likely to be complex, resembling the ‘feedback loops’ often found in systems networks: companies that cover more operational factors will be more mature with regards to DfRem integration, and in turn companies at a higher level of integration maturity will implement more integration operational measures such as DfRem in design reviews or improved communication.

Therefore it could be of value to take this concept of integration maturity further, and develop a DfRem integration maturity model. Organisational maturity models help companies determine their level of maturity with regards to one or more company processes. They can then help the company determine the next steps required for process improvement.

BSI 15504-7:2008 provides guidance on the assessment of organisational maturity, and defines the term as the *‘extent to which a company consistently implements processes within a defined scope that contributes to goals’* (British Standards Institution, 2008). The standard provides a scale of organisational maturity, from ‘immature’ to ‘managed’ to ‘innovating’. A company can use the maturity model to evaluate process capability (how well a process e.g.

design reviews meet goals e.g. better integrated DfRem), and ultimately organisational maturity (how well the company implements the processes).

A similar study has explored organisational maturity with regards to ecodesign (Pigosso and Rozenfeld, 2011). In this paper the authors have identified a similar need for improved ecodesign integration and a roadmap that will help companies achieve continuous ecodesign improvement. Like BS15504-7:2008, their maturity model also has five levels of maturity, ranging from no ecodesign experience to recognition of the importance of ecodesign to integration of ecodesign at a corporate business and product level.

The outcomes of this research did not extend to the development and design of a DfRem maturity model for two reasons. Firstly, as this research is exploratory and theory building, it was decided that the research findings could not be accurately and rigidly categorised in such a manner. Furthermore, the research findings, and the author's overall reflections and conclusions, did not verify that designers or managers or OEMs actually *want* a DfRem maturity model. The models described in both BS15504-7:2008 and (Pigosso and Rozenfeld, 2011) are highly formalised, complex and based on the quality concept of 'plan – do – check – amend'. Whilst this approach is perhaps appropriate for a wide-ranging concept such as ecodesign (which may include remanufacturing issues), realistically speaking DfRem as a single design concern is not currently of high importance in a typical company's agenda and therefore any proposed measure or tool or model must take this into account.

7.4 Final Conclusions

This research set out to achieve the aim:

'To gain an understanding of the operational factors that enable design for remanufacture (DfRem) to be better integrated into a company design process.'

Following a multiple case study methodology with three companies from the mechanical / electromechanical industry sector, this understanding was built firstly by identifying the external and internal operational factors which influence DfRem integration. Understanding was then further enhanced by the definition of the relationships between these factors, and the development of a network model which can effectively communicate the new knowledge to the beneficiaries of the research.

Overall, the findings from this research have generated some key lessons or messages regarding DfRem practice and DfRem academia:

The research has firstly confirmed that operational factors are indeed significant when considering DfRem integration, as well as the technical issues more commonly addressed in previous DfRem literature. The research findings provide awareness of the external factors which influence the decision to design for remanufacture, and the internal factors that design managers may wish to act upon to improve DfRem integration success. The research then went on to explore how this knowledge should be presented to practitioners— a reference model that is simple and visual yet informative, with no prescribed ‘route to success’ but instead a portfolio of options to suit a wide range of companies at different stages of integration maturity.

The research has also successfully highlighted the differences between ecodesign and DfRem as discussed previously in this chapter. Although there are many similarities, it cannot be assumed that ecodesign research is inter-changeable with remanufacturing research.

Upon reflection, the research has also highlighted some less positive messages for remanufacturing academics and advocates. It was clear from the case studies that DfRem is certainly not a high-priority issue within the design process, and this assertion included Company A, that currently designs for remanufacture. This does not mean that DfRem does not have value or is not worth investment in time and resources, however it is an issue that academics must take into account when proposing DfRem integration or the implementation of methods and tools. Any DfRem solution proposed must correspond to the willingness of industry to participate. This of course may change over time, for example if more stringent end-of-life legislation were to be implemented.

Another related issue that arose from the research was the fact that some companies simply do not feel that DfRem applies to them, because their products are already successfully remanufactured. Of course, just because a product may be remanufactured through ‘serendipity’ does not mean that the product is optimised for the remanufacturing process, but such perceptions can be difficult to overcome and again must be taken into account when prescribing DfRem solutions. At the same time, although much of these views could be attributed to perception, it is likely to be the case that some companies have more to gain from DfRem than others.

The main knowledge gap which spurred this research was the lack of thinking outside the 'design tools' box in DfRem research. From the case study findings it became clear that design tools are of limited use and interest to design engineering teams, and instead some basic knowledge of current remanufacturing practices combined with some simple guidance and regular, quality communication is the preferred approach to a design task which was considered straightforward but low-priority in the design process.

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Appendices

Appendix 1: Case Study Reports

1A: Company A case study report

1B: Company A response

1C: Company B case study report

1D: Company B response

1E: Company C case study report

1F: Company C response

Appendix 2: Evidence Tables

2A: External operational factors

2B: Internal operational factors

2C: Role-ordered evidence tables

Appendix 3: Publications

3A: List of journal publications

3B: List of conference papers

Appendix 1: Case Study Reports

To improve the reliability of the information gathered from case studies, each case study company was presented a case study report following the final visit to its facilities. The reports were intended as a brief summary of the key relevant facts and opinions gathered about the company.

The reports were emailed to aftermarket management who had been interviewed for the research. It was considered of highest importance that aftermarket reviewed the reports, as these employees have an insight into both design engineering and remanufacturing. However, the reports were also passed on to design engineering management to ensure that the designer perspective was effectively captured.

Note: Specific references to names, locations etc have been removed to maintain anonymity.

1A: Company A case study report

Business: Design and manufacture of diesel engines, primarily for the power generation market. Two operations, one producing [Company A] engines, the other customising [parent company] brand engines imported from USA.

Company Background: [removed to maintain anonymity]

Company's current remanufacturing activity

The [Company A] engines produced by the [Location 1] site are mainly remanufactured at the [Location 2] facilities. At present it is only the cylinder heads of [Location 1]-produced engines that are remanufactured. Whole engines produced at the [Location 3] site are also remanufactured at another [parent company] facility. The difference between the [Location 1] and [Location 3]engines is size and life in use- [Location 3] engines are smaller with shorter lifecycles, meaning whole engine remanufacture is a more feasible option. Because [parent company] is the parent company of [Company A], the company retains ownership of the returned cores and [Location2] is provided with the necessary design drawings. [Company A] has been remanufacturing its engines in some form or another for many decades.

Company's current 'design for remanufacture' (DfRem), activity

[Company A]'s products are naturally suited to remanufacture because the diesel engines are very high value and predominantly metal. They are mainly assembled manually meaning fastening and joining methods are generally easy to disassemble in a non-destructive manner. Furthermore, it is important that such high value engines can be taken apart for regular maintenance, meaning they must be designed with disassembly in consideration. Also, remanufacture is a profitable route to market for the company. These are the reasons why the design engineers at [Company A] believe remanufacturing has 'always' been considered during the design and development phase. The DfRem standards literature that is followed by [Company A] designers today was developed by the company many years before the [parent company] takeover, these standards are still considered suitable as the main design of the diesel engines produced today were developed in the 1980s.

DfRem considerations such as disassembly and additional material are outlined in the product design specification (PDS) document. For example, allowances for crankshaft dimensions as outlined in the design standards, and the use of oversized bearings that can be replaced with smaller bearings by the remanufacturer. DfRem is also part of [Company A]'s 'design for environment' checklist, which is completed for each component design. The design engineering staff are given some environmental training however most DfRem knowledge is learned from experience and from other engineers.

There are however, some components which cannot be designed for remanufacture due to the demands of their functionality. For example the high tolerances of piston grooves, combined with a high rate of wear render these components not suitable for remanufacture.

Key DfRem Motivators and Enablers

The decision to remanufacture, and therefore design for remanufacture, is very much driven by customer demand. [Company A] produce high value engines and their customers expect long life at an affordable price, as well as the provision of affordable spare parts. As a result, marketing endorse remanufacture, and so DfRem becomes part of the PDS. As mentioned above, [Company A] products are naturally suited to remanufacture and so their designs do not require extensive alteration to become more remanufacturable. Furthermore, [Company

A] has access to a wealth of knowledge and experience from its own history in remanufacturing and from its parent company, that has become highly competent in running a remanufacturing business over many years.

The ‘design for environment’ checklist could also be considered a motivator as designers are expected to consider this throughout their design work. At design reviews the checklist is used to demonstrate that issues such as DfRem have been considered. Whether DfRem has been achieved or not is decided by the designer and the manager who checks and signs the checklist. Furthermore, the checklist aids [Company A] in demonstrating they are achieving their ISO 14001 environmental standards during audits. Annual renewal of ISO 14001 accreditation is important for company reputation.

Overall Management View

Although not the top concern, remanufacture and DfRem are of significant importance in the [Company A] design process, and as long as there is customer demand [Company A] will continue to remanufacture. DfRem is not a particularly difficult or troublesome task, and it is widely understood why DfRem is a worthwhile concern. There are no specific DfRem tools in use (except for the DfE checklist) and this is not a problem. Rather than a distinct design activity, DfRem is viewed as part of the design process, just one of the many considerations in the PDS.

1B: Company A Response

You replied on 01/03/2012 21:29.

Sent: 01 March 2012 14:01

To: Gillian Hatcher

Hi Gillian,

Hope you are well..........I can't believe it was August when you were here!...........how time flies......

I think your text is accurate but you may wish to include China as a place where we manufacture, also. we are opening a manufacturing plant in India later this year.

If you wish to discuss, please feel free to call me.

Kind regards,

Malcolm

CPPD Technical Services Manager
Configuration Management

You replied on 05/03/2012 11:44.

Sent: 02 March 2012 13:19

To: Gillian Hatcher

Cc: [redacted]

Gillian,

Things are good here, hopefully you are also OK.

There is a Product Objectives document that Global Product Support have input to, this requests many requirements for example serviceability and brand, but also the need for an overhaul and remanufacturing solution that basically results in a validated emissions compliant solution.

You mention the following...... The key time at which remanufacturability will be assessed is the 'serviceability audit', carried out by [redacted].

I'm not sure this is technically correct because whilst we do carry out the serviceability audit this generally too late in the process to impact the product design. Therefore we use the Product Support engineers (who used to work for me, but have since moved to the New Product Introduction team) to collaborate with the design team to ensure the overhaul and remanufacturing requirements are met. We in Product Support have a service strategy and design guidelines document that provides the Reman requirements required in the above mentioned product objectives this also ensures consistency across the whole product range.

Just to clarify [redacted]

Regards

Dave [redacted]
Service & Parts Information Manager

[Amendments were made to the case study report]

1C: Company B case study report

Business: Manufacture of pumps for upstream and downstream oil, nuclear and conventional power, water and industrial, minerals and mining sectors.

Company Background: [removed to maintain anonymity]

Company's current remanufacturing activity

Although not normally referred to as 'remanufacturing', [Company B]'s aftermarket services match the definition of this process, i.e. returning used pumps to original spec or better. This is carried out both by contractors in other countries and at the service bay within the manufacturing facilities. Much of this work involves replacing worn parts with newly manufactured components, as opposed to carrying out reprocessing activities such as cleaning, re-boring, resurfacing etc. However there are occasions when such rework can be carried out for particular components. For pumps designed for the nuclear industry, the frequency of 'replace with new' may be due to the tighter tolerances which render reprocessing methods such as re-boring impractical, as well as tighter controls meaning nuclear pumps are typically treated on-site rather than at a service facility. For pumps designed for the oil industry, new components are most often chosen over reused as large budgets can more easily accommodate this choice.

Company's current 'design for remanufacture' (DfRem) activity

[Company B]'s pumps are well-suited to the remanufacturing process, being of high value (worth investing in) and made of durable materials (able to withstand both the remanufacturing process and multiple lifecycles). There are also several general 'design for maintenance' features which are typically found in [Company B] pumps, such as removable sleeves, which are beneficial to remanufacture. Design engineers are expected to consider the general maintenance and servicing of new products, and [Company B] pumps are designed for easy disassembly and access for maintenance. Design engineers are not specifically trained in meeting these requirements, instead these issues are considered a basic part of their day to day work, something that can be learned easily through experience.

However, [Company B] pumps are not specifically designed to enhance the effectiveness and efficiency of remanufacture. Design engineers are not incentivised to consider specific remanufacturing issues because there are currently no product specifications relating to pump remanufacture, and no formalised systems, methods or tools used by design engineers to enhance the remanufacturability of a product at the development stage. Design engineers do however have a general understanding of remanufacturing and DfRem issues.

Key 'design for remanufacture' (DfRem) motivators and enablers

A key driver to design for remanufacture at [Company B] would be the fact that aftermarket is the most profitable part of the business, suggesting that investing some time in ensuring pumps can be remanufactured efficiently and effectively may be worthwhile. Also, the increasing pressure upon the end users of [Company B] pumps to improve efficiency and reduce carbon footprint, may begin to have an impact upon customer requirements for the end-of-life treatment of their purchases in the future.

An advantage design engineers working at the [case study] site have is the fact that aftermarket and the service bay are located on-site. This proximity creates an opportunity to establish regular, quality feedback between the two parties, should there be a need to discuss design-related issues. At present such communication is rare, although engineering management do occasionally visit the service bay to discuss technical issues.

There are also some opportunities for future DfRem integration into the [Company B] design process, based upon existing practices. Checklists used during design reviews could be adapted to include remanufacturing considerations. Also, [Company B]'s 'Incident Control Report' system could be utilised to encourage feedback between aftermarket and OE engineering, as well as continuous improvement of pump remanufacturability.

DfRem barriers and challenges

The incentive to design [Company B] products specifically for remanufacture is perhaps not as straightforward as in companies operating in different industries. Whilst aftermarket services are a crucial part of [Company B]'s business, there is no specific customer demand for remanufacturing services at the design specification stage. This is due to the nature of the oil and nuclear industry in general- orders are placed by 'Engineering and Procurement Contractors', who are removed from the end user, meaning they have little interest in the product’s servicing or end-of-life treatment. Furthermore, these EPC customers often have very specific and demands, leaving little room for ‘additional, nice to have’ features such as DfRem. As a result, DfRem is not normally included in the design specification and design engineers are not expected to consider remanufacturing issues as part of their work, unless the customer includes such requirements in their specifications.

The current organisational structure also creates barriers to DfRem. OE Engineering and Aftermarket are separate business units, and communication between the two parties is not regular or formally organised (for example aftermarket are not present at design reviews). Generally communication is not deemed necessary, however some opportunities to exchange information that could improve the ease of servicing pumps may (in theory at least) be missed. At present, any communication that does take place is not normally direct, instead it is usually through warranty personnel. As well as communication issues, the [Company B] organisational structure may possibly challenge the incentive to design for remanufacture, as there may be an element of competition between aftermarket, who want to remanufacture products, and OE engineering who usually prefer to sell a new product (as long as they believe it to be a good option for the customer).

Overall Management View

Although DfRem is not formally recognised as part of the [Company B] design process, there are several design features normally included in pump designs that enable remanufacture and aftermarket services are a very important part of the business. There could perhaps be more communication between aftermarket and OE engineering, however in general [Company B]’s products are already well-suited to remanufacture, and ‘DfRem’ as a formalised part of the design process is not a top priority at the present time. Whilst integrating DfRem into the design process could potentially bring benefits to [Company B], there is a lack of clear evidence for what these benefits would be and therefore whether DfRem is something worth investing more energy into in the near future.

1D: Company B response

You replied on 20/06/2012 11:13.

Sent: 10 April 2012 07:56

To: Gillian Hatcher

Attachments:

RE: [Company B] case report

Gillian, please accept my apologies for not responding sooner, I trust this hasn't caused you too much of a problem. I have attached some of the internal comments in a thread of e-mails between Crawford, Andrew & myself on your draft report. You will see that in some cases they are contradictory (we can't agree on everything!) and perhaps confusing. If you wish to discuss further, let me know and we can arrange a further chat.

Regards,

Robin [redacted]
Head of Engineering - Upstream Oil & Gas

[An email requesting some clarification was sent following feedback from the attached internal email thread]

You replied on 13/07/2012 12:44.
Sent: 06 July 2012 13:24
To: Gillian Hatcher
Gillian,

Based on your clarifications of remanufacture and DfRem then I would confirm agreement with your three statements.

The level of DfRem for each pump will also vary depending on market/specifications and client and not generally by our company. For instance the water market is very competitive for initial startup cost which means the pump will usually be supplied with less replaceable wear parts as that of a pump in the oil industry.

Best regards,

Andrew
Principal Engineer, Engineering Services

Gillian,

The report reads very well. I would only have some minor comments.

- [redacted]

- Section 3 - Your statement about the oil industry makes it sound like they spend money because they are cash rich. The market sector will still require justification as to the replacement costs. The main driving factor for the oil industry is with regards to process downtime where millions of pounds can be lost every day if production is not available. If process downtime is at risk the quicker repair would be considered. If time is not critical then generally components will be replaced with new as this is considered less risky for future reliability. This is perhaps general for the industry and may not be the same for every client who will have different views on strategy and costs.
- Section 4 - Most of our employees will go through a basic pump introduction course. This will go into details about replaceable components, reasons and benefits. The part about no training and part of the day to day job needs to be changed. Perhaps this is in contradiction to other opinions from Robin or Crawford you have received before?
- Section 4 paragraph 2 - International standards will give guidance on what level of DfRem needs to be adopted. Generally though this will be left up to the client to specify and we will design accordingly for cost reasons. I agree that there is no guidance as to whether we should be designing for upfront reduced costs or potential aftermarket spares sales in the future.

- Section 4 (you have two section 4's) - Not sure who gave you the following quote 'At present such communication is rare, although engineering management do occasionally visit the service bay to discuss technical issues.' I would disagree as it is a regular occurrence for Engineering support on the service centre when requested.

Hope this helps.

Best regards,

Andrew
Principal Engineer, Engineering Services

[Amendments were made to the report]

1E: Company C case study report

Business: the design and manufacture of rigid and articulated dumper trucks, primarily for use in mining and quarries.

Company Background: [removed to maintain anonymity]

Company's current remanufacturing activity

[Company C] is not currently involved in remanufacturing. Whilst third parties are known to remanufacture or refurbish [Company C] parts for resale, and there is a second hand market for [Company C] products, the original equipment manufacturer (OEM) has no involvement or stake in these activities.

[Company C] do offer their customers a service package that will enable them to prolong the life of their purchase, however servicing currently involves the replacement of worn parts with newly manufactured spares.

It has been noted that [Company C] products, for example dumper truck axels, are suited to the remanufacturing process, as demonstrated by top competitors in the industry who are already profiting from this service. Any move toward remanufacture at this early stage would require commitment from top management. A barrier for [Company C] is the cost of initial set-up, combined with the uncertainty of economic feasibility of such a business venture. The company require more information about the business case for remanufacture before any decisions could be made. Due to the expected cost of remanufacture start-up, any future remanufacturing activity is likely to be carried out under a contractual agreement with an independent company.

Company's current 'design for remanufacture' (DfRem) activity

[Company C] products are not currently designed for remanufacture, for example components do not feature additional material that could enable surface skimming or re-boring. The obvious reason for this is that the products being developed today are unlikely to be put through a remanufacturing process. However, [Company C] design engineers are required to consider the serviceability of a new product, and therefore design for simple, non-destructive disassembly. This product characteristic would aid any future remanufacturing activity.

Key 'design for remanufacture' (DfRem) motivators and enablers

First of all, many of the components of Company C products are naturally suited to the remanufacturing process: they are durable enough to withstand multiple lifecycles and are of high value, driving the demand for a prolonged life in use. The products being manufactured in [case study location] are also technologically stable- most of the design work carried out today involves the development and improvement of long-standing designs. This development work provides an opportunity for DfRem principles to be incorporated into [Company C] products.

Another enabling feature of the [Company C] design process is the 'serviceability reviews', during which a design is reviewed in terms of its suitability for disassembly and servicing. This existing practice could be adapted to include remanufacturability issues.

Furthermore, although [Company C] design engineers and managers do not currently have experience of designing for remanufacture, the company does hold extensive knowledge of the disassembly and servicing of many components, e.g. transmissions, through the development of their aftermarket training centre.

DfRem Barriers and Challenges

The main barrier to design for remanufacture at [Company C] is the simple fact that the company do not currently remanufacture their products. Although 'proactive' DfRem- in anticipation of remanufacturing in the future- could be of benefit to the company, as long as the feasibility and/ or timescale of remanufacturing set-up remains unclear, there is no strong incentive to begin designing for remanufacture now.

Another barrier is the fact that several of [Company C] dumper truck key components, for example the engine, come from a supplier and are therefore not designed by the in-house team. These parts may be suited to remanufacture but [Company C] will have less control over DfRem in these cases. However, some supplied components are custom-made for

[Company C], and in these cases remanufacturability could be part of the design specifications.

If DfRem were to be integrated into the [Company C] design process, a challenge may arise from design priorities. Like all companies in this industry, [Company C]'s main focus today is upon complying with Tier 4 emissions legislation whilst continuing to meet customer demands. There is currently no legislation demanding that manufacturers of off-road vehicles consider the end-of-life of their products, and therefore it is likely that remanufacture will not be of top priority in any new product development. Ensuring remanufacturability when faced with design conflicts may become challenging in this case.

Another challenge in DfRem integration would be ensuring that design engineers and management feel able to carry out this task. Staff require some knowledge and experience of the remanufacturing process in order to understand how [Company C] products may be improved, as well as the provision of both time and tools to carry out DfRem effectively. What makes this challenging is the fact that the design team in [case study location] is small with little flexibility for including 'nice to have' design features, plus [Company C] do not have a history of carrying out 'DfX' in general.

Overall Design Management View

Remanufacture, and therefore DfRem, is a real possibility for [Company C]'s future. However any plans for such activity are at their earliest of stages, and it is in the hands of top management to set the ball rolling. Until remanufacturing is a confirmed reality for the company, DfRem will remain irrelevant to the development of new [Company C] products.

There are certainly opportunities for remanufacture within [Company C]'s current product portfolio, and many areas for potential improvement with regards to remanufacturability. If and when remanufacturing becomes part of [Company C]'s service offerings, the main challenge will be finding the flexibility to integrate DfRem in a way that compliments, not hinders, other design priorities.

1F: Company C response

You replied on 27/03/2012 17:13.

Sent: 26 March 2012 19:00

To: Gillian Hatcher

Hi Gillian,

Hope you're doing well.

Apologies for the delayed response. I should have got back to you when I said I would.

All and all, the piece fairly and accurately details where we sit with regards to remanufacturing. It is an area for growth and can add value to our bottom line while supporting our customers to keep their operating costs lower, helping them make the most of their investment.

Only little detail is on our net sales. We've recently had last year's numbers released, which finished at $6.5 billion for 2011.

All the best, if you need anything else please let me know.

Cheers

Kenny
Global Product Manager
Off-Highway Rigid Trucks

Appendix 2: Evidence Tables

2A: External operational factors

Case Study	**External operational factor**		
	~~**Competitiveness**~~	**Supplier Commitment**	**Customer demand**
Company A *Interviewee initials*	NO No strong evidence was gathered that Company A do DfRem specifically for competitive reasons.	YES *DE* -Suppliers have no involvement in reman and therefore have no incentive to design components for remanufacture. -Also, the cost of buying spares from suppliers was cited as a major issue which makes reman less profitable, therefore less influence in design process.	YES *AT, PS, JE, MS, NW, SC, PB* -Customer demand for long life/ reman/ low cost spares is cited as a main driver. This means they get marketing support, which means DfRem gets into the PDS. -For Location 3, the 'customer' is [parent company], who are very demanding, including for multiple lifecycles.
Company B *Interviewee initials*	NO However, one designer has noticed that competitors are being selected due to their environmental credentials, mainly carbon footprint.	NO No evidence was gathered.	YES *RS, CG, BC* -Interviewees say customers have ultimate power: aftermarket can request a design change but the customer can refuse. -Customers are more interested in 'here and now'. - There is customer demand for reman as it saves companies so much money, but this demand isn't coming from the 'new manufacture' customer.
Company C *Interviewee initials*	YES / <u>NO</u> *KP* Company C are aware that their competitors are remanufacturing, so it is something they may need to start preparing for. Their main competitors are much larger, and perhaps to reach that level reman is something they'll need to invest in. However, this relates to reman, not DfRem.	YES *KP, MC* Many of the most 'remanufacturable' components are purchased by suppliers, so there is less DfRem that can be done in-house. These parts mainly purchased off-the-shelf so Company C has less control over design.	YES *KP, MC, CB* Don't currently feel there is customer demand, and this is a key point. Particularly their further afield customers prefer landfill. However, customer demand in general is important and other customers do demand a full service package to prolong the lives of their trucks.

Case Study	External operational factor (cont)		
	~~**Legislation**~~	~~**Marketing**~~	**Profitability**
Company A *Interviewee initials*	NO *PS, JE, MS, SB, PB, DE* There is no specific legislation to drive DfRem, nothing on the horizon. There is ELV/WEEE pressure on customers but the drive is diluted when it comes to engine design. YES (barrier) -Emissions legislation (or the pressure to meet other legislation) in the absence of reman legislation drive pushes DfRem further down the priority list.	YES / <u>NO</u> *AT* Mentioned that it is marketing support that results in DfRem being in the PDS, as this is written as in collaboration.	YES *MS, SB, NW, SC* There is more drive in Location 1 where reman is more profitable (bigger, more valuable engines) than at Location 3. Cited as incentive to do DfRem frequently.
Company B *Interviewee initials*	<u>NO</u> / YES *AS, RS, JW* -General answer to question was 'no' there are no legislative drivers. -However, there were mentions of 'secondary' legislation that could have an impact such as ASME requirements to accommodate service, or power stations (customers) to be more efficient. However interviewees state this has little or no impact on DfRem. -Engineering manager says it is legislation that would drive CU to DfRem in future.	NO No evidence.	YES *BC, CG, DC* Aftermarket activities are more profitable than new manufacture. They have higher profit margins. Some interviewees said they could see the logic in DfRem from this perspective, although one engineering manager wanted more evidence.
Company C *Interviewee initials*	NO *KP, MC* No legislative pressure, don't see this being an issue any time soon (ELV does not apply to off-road).	NO No evidence.	NO *KP* Company C does not yet know if reman is a profitable business venture for, and concerns it would not be economically viable act as a major barrier according to interviewees.

Case Study	External operational factor (cont)		
	Environmental impact	**Suitable products**	**Engineering resource**
Company A *Interviewee initials*	YES *PB, JE, PS, AT* -Sustainability is a core company value, but it isn't a main driver. -They use reman to promote a 'green' company image. Designers talked fluently about this. -DfRem is in the company DfE checklist and part of ISO14001 standards.	YES *DE, JE, PS, MS, SB, PB* There is more DfRem drive in Location 1 as the engines are most suited so it makes the most sense to maximise the opportunity.	NO No evidence was gathered to suggest this.
Company B *Interviewee initials*	NO *CG, DC, AS* -Customers have no interest in environmental issues. -One designer felt this was something Company B would have to take more seriously in the future.	NO (negative impact) *DM, RS* Because their products are highly suited (and historically had DfRem features included) many interviewees didn't see the need for DfRem.	NO No evidence was gathered to suggest this.
Company C *Interviewee initials*	<u>NO</u>/ YES *CB* Not a key concern, no evidence. However, some customers are beginning to make inquiries regarding proportion of recycled materials etc.	<u>NO</u>/YES *CB, MC, KP* Although suited, there are too many other issues that get in the way. However, the fact the products theoretically could be remanufactured is making some managers start to think about the possibility for the future.	YES *KP, MC, ST* Because the design team are considerably smaller than their closest competitors, reman would be a very big investment for them, and not one they see being feasible any time soon. Therefore they don't see the need for 'proactive' DfRem as there is no certainty they will ever be able to afford reman setup.

2B: Internal operational factors

Case Study	Internal operational factor			
	~~**Liaison**~~	**Priorities**	**PDS**	**Remanufacturer commitment**
Company A *Interviewee initials*	YES *SR, DE, MD, JM* -It's the main point of contact between the two parties. The liaison will co-write the reman spec and carry out serviceability audits. -Who this person is was cited as an issue. -The need for a liaison (instead of direct communication) was also questioned. -There is also concerns of what will happen when the liaison retires.	YES *AT, DE, JE, PS, MS, SB, MD, JM* -Emissions legislation is leading to a lot of trade-offs. -Reman is still low priority, and will most often be compromised for cost or function. -Reman is not the customer, and meeting customer requirements is top priority. -They are under constant pressure to improve engine performance, they feel this is in contradiction with DfRem.	YES *AT, DE, JE, PS, MS, SB* -DfRem being in the PDS is what ultimately makes designers consider it- it's part of their job. -The PDS gives designers specific instructions. -Designers are involved in the PDS writing process, so they are taking an active role in the decision to DfRem. -The liaison also gets a say in the PDS. Worth remembering however that designers don't have to stick to the PDS exactly- compromises are permitted.	YES *DE* -Liaison said that whilst it is difficult to motivate designers, it is also difficult to get reman interested in product development. They have no interest in attending design reviews, as the discussions won't be relevant to them for several years. Reman management feel they don't have time to look this far into the future.
Company B *Interviewee initials*	NO N/A	YES *BC, CG* -Very demanding customer requirements put DfRem very low down in the priority list. -The general design priorities are customer specs, commercial drives and manufacturers design codes.	YES *BC* -Their PDS from the customer is very demanding, meaning there is little room left for other issues like DfRem.	YES/ NO *DM* Remanufacturer management did not see the need for DfRem / improved communication etc.
Company C *Interviewee initials*	NO N/A	YES *KP, MC, ST* Even if DfRem was on the agenda, it would likely be low priority.	YES *ST* At the moment, designers simply are not required to DfRem via PDS, so with a busy schedule, why would they do it?	NO N/A

Case Study	**Internal operational factor (cont)**		
	Design Reviews	**Design tools**	**~~Historical Data~~**
Company A *Interviewee initials*	YES *DE, MD, JM, PB* -Design reviews are when the liaison gets a chance to argue the case for DfRem- the timing of his 'serviceability audit' is crucial. -The DfE checklist, which includes DfRem, is looked at in design reviews.	YES *AT, PS, JE, SB, MS, PB* -CAD allows them to easily add additional material. -The DfE checklist at least ensures DfRem is considered to some extent. -They have guidelines booklets, although they aren't often referred to	YES *MS, SB* -The general DfRem guidance given to designers is largely based on historical data which has not been updated for decades.
Company B *Interviewee initials*	YES *AS, RS* -Design reviews are the only time a reman issue may be raised by a member of staff. -However, design managers are busy and do not always stay long enough to get to these finer details.	NO No evidence.	NO No evidence.
Company C *Interviewee initials*	YES *ST* The closest to DfRem Company C has is a serviceability audit during design reviews.	NO No evidence.	NO N/A

Case Study	Internal operational factor (cont)		
	OEM-Reman Communication	**Organisational Structure**	**~~Training~~**
Company A *Interviewee initials*	YES *PSC, SR, DE, JE, PS* -Reman say that designers are often very resistant to DfRem / reman in general, but visiting the facilities can even make them enthusiastic. -They have a liaison who pushes for DfRem- he is in regular contact with reman. This is mainly how designers consider DfRem. -Liaison cites the fact reman feel disconnected / unconcerned with design reviews as a DfRem issue, as they aren't there to discuss when new products are being developed. -Liaison feels the fact he exists is bad as it would be even better for DfRem if the two groups communicated directly.	NO Structure was not specifically raised, except maybe the fact OE mainly deal with warranty failures which are quite different.	NO *AT, MD, JM* -They feel that learning through experience, with some supervision from the most experienced designers is sufficient as DfRem is not a particularly challenging task.
Company B *Interviewee initials*	YES *JW* -They have very little communication with aftermarket and are further removed from reman, due to the business units. [des--aftermarket--reman] -Aftermarket cited that communication could be improved. -The need to communicate is reduced by the fact aftermarket have their own engineers.	YES *AS, RS* -Separate business units means OE and AM are in some ways competing against one another. (Reman disagree) -Changes to company structure (merger) have distanced the two departments. -The oil and nuclear industry have 'middle men' with no interest in reman, therefore no 'customer demand'. -OE only deal with warranty failures, which are different.	NO *RS* - Designers do learn through experience rather than training, but they don't see this as a problem. Design reviews are where younger designers can learn from more experienced staff members.
Company C *Interviewee initials*	NO N/A	NO No evidence.	NO N/A

Case Study	**Internal operational factor (cont)**		
	Motivation	**Knowledge & Understanding**	**Management Commitment**
Company A *Interviewee initials*	YES *AT, DE, MD, JM* - Designers are very protective. - Being motivated by seeing the reman process has had a positive impact on designers. - Aftermarket cite as a major issue. -Location 3 smaller engines are less remanufacturable, so designers see as an unnecessary complication. Additional pressures are de-motivating. -'Reman is not the customer' and the customer is most important in designer's minds. -Location 3 designers are less motivated because it is more challenging for them.	NO / YES *PSC, SR, JE, PS, MD, JM* -Designers were knowledgeable, could explain significance of DfRem, did not find it difficult. -Said they learned through experience, but this wasn't a problem. -Mistrust of reman's ability to bring high-performance engines back to as-new condition.	NO No evidence was recorded to suggest management commitment was a barrier. This is not to say management play no significance. The management I spoke to were in favour of DfRem, so interviewees did not cite as an issue.
Company B *Interviewee initials*	YES *BC, DC, RS* -Designers and managers said they simply had no motivation to consider DfRem- it wasn't part of their brief/ job description. Individuals don't think it is relevant to them. -Top engineering management admitted it was not important to their designers compared to function and cost.	NO There was no strong evidence that understanding was an issue, but then most designers here have never been asked to display any DfRem skills. However, the designers I did speak to had a little trouble grasping the concept when I spoke to them.	YES *CG, JW, RS* -One designer felt that management were short sighted in not prioritising DfRem. -Management did not prioritise reman, or stay in design reviews long enough to discuss reman. -However, top engineering managers who have an interest in the overall performance of the company have a little more commitment to it. -Top engineering manager said he needed more evidence of the benefits of DfRem before he could seriously consider it.
Company C *Interviewee initials*	YES *KP, ST* -As long as there is no reman going on, there is no motivation for designers to consider DfRem.	YES *CB, MC, ST* -Because they have never had any involvement in reman, managers have little knowledge of DfRem, would want basic info. -One of the two designers understood DfRem, the other did not immediately know what reman was.	YES / NO *ICB, MC, KP, ST* -Reman is being discussed at a top management level, but they have limited knowledge about DfRem. - Any decision to remanufacture is going to have to come from top management first to get the ball rolling.

2C: Role-ordered evidence tables

Company A

EXTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management	Remanufacturing Management
Customer demand	This was cited as the main reason for doing DfRem, it was the reason given why it 'made sense to do it'.	Designers understood that the reason they were expected to do DfRem is because of customer demand, and they accepted this, even if some designers felt DfRem caused difficulties.	Aftermarket have an understanding that there is customer demand, but it is not integral to their drive to encourage DfRem; in effect they are already 'sold' on the idea.	Reman understand that there is customer demand (afterall they have evidence in their sales), but it is not an integral part of their motivation.
Profitability	In general managers assumed reman must be profitable and therefore worth considering in design, but they had very little knowledge of facts and figures regarding this.	Same response as with managers	Aftermarket are absolutely sure reman of profitable and worth investing in.	As before (aftermarket)
Environmental impact	Design managers are well versed in discussing company sustainability and had access to a lot of information on this. However they were also able to stress that it isn't a main driver.	Same understanding as the managers, but they have less involvement/ interest in meeting parent company core values.	NONE	Reman are also keen to sell remanufacturing on its environmental credentials, and view themselves as contributing to one of the company's core values.
Suitable Products	Particularly managers at Location 1 could see that reman was an obvious choice for their engines so it made sense to design for this.	Similar to before but not discussed so much.	As before	It doesn't matter to reman so much if it's naturally suited, as they feel they can meet almost any challenge given to them.
Engineering Resource	NONE	NONE	NONE	NONE
Supplier Relationship	NONE	NONE	Cited this is a big issue when it comes to the overall remanufacturability of the engines, something the company have little control over.	NONE

INTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management	Remanufacturing Management
Motivation	Managers were clear that they had the capabilities to do DfRem, but it was not top of their priorities and was personally not a major concern to them.	Designers at Location 1 were motivated, whereas Location 3 were less so, but both groups had similar levels of knowledge. The difference was an appreciation of the importance and potential benefits.	Remanufacturing liaison said he found his job unrewarding at times because it is often so difficult to motivate designers to care about DfRem issues, because they have so many other issues to consider first.	Reman felt strongly that motivation amongst designers and managers was an issue, they felt they were simply not interested in reman's needs, protective over their designs.
Knowledge and Understanding	They did not feel that K&U was an issue for them or their staff.	Were able to demonstrate good knowledge of the reman process and its significance to the company, said they had no technical problems with DfRem.	Did not feel this was a major issue.	NONE
Management	NONE	NONE	As well as designer motivation, the liaison feels that DfRem is a 'lost opportunity' because the management in general don't care enough about it.	NONE
OEM-Reman Communication	Did not see the real need to communicate with reman.	Were not aware of any communication, had never seen the reman process.	Most frustrating part of his job, getting the two to collaborate and communicate effectively.	Felt they were not always listened to or included in decision-making, cited as a major barrier.
Organisational Structure	NONE	NONE	NONE	Brief mention of issues regarding warranty failures being designed for, not reman failures.
Design Reviews	This was cited as the main opportunity for designers to pick up experience, and the main instance at which DfRem would be assessed.	Similar to before, but less awareness. Say the serviceability audits are the main, really only, time DfRem is seriously considered.	This is the liaison's main opportunity to carry out a serviceability audit and communicate with design engineers.	NONE
Design Tools	The checklist and guidelines booklets were mentioned, but I got the impression they weren't considered that significant, especially the guidelines.	CAD mentioned as well as checklist, but again not a big deal made out of it.	NONE	NONE
PDS	NONE	The designers at Location 1 say this	They get a say in the writing of the PDS	NONE

		is basically the main reason they are willing to do DfRem, and they get a say in the writing of this so they understand the importance of DfRem.	which is significant in ensuring DfRem is considered.	
Priorities	A major issue- DfRem is low priority compared to other design issues, so there is little time to make room for it.	As before, except expressed from the perspective of being under pressure to deal with other issues, making DfRem seem like an inconvenience (at least at Location 3).	Admit it's low priority and this causes issues.	NONE
Reman Commitment	NONE	NONE	Aftermarket feel that reman are almost as much to blame, as they are not looking far enough into the future.	NONE

Company B

EXTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management	Remanufacturing Management
Customer demand	Management felt that there wasn't strong customer demand for reman.	NONE	Mentioned, not discussed in detail.	Remanufacturing were absolutely sure of customer demand from end users who want a high quality service at an affordable price.
Profitability	Awareness that aftermarket is the most profitable part of the business.	NONE	Confirmed that reman is very profitable.	As before- reman has very high profit margins
Environmental Impact	NONE	Some mention by one designer that he personally feels the company needs to be able to market itself as sustainable.	Say customers have no interest in sustainability.	Says whilst reman surely has environmental benefits, it's never been considered important.
Suitable Products	Management feel this is a reason not to do DfRem.	NONE	NONE	Reman say the products are great as they are, no design problems to do with DfRem. But is this just because they are used to things 'the way they've always been'?
Supplier Relationship	NONE	NONE	NONE	Said suppliers were not a problem- for some parts will be returned to the supplier to remanufacture themselves.
Engineering Resource	NONE	NONE	NONE	NONE

INTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management	Remanufacturing Management
Designer Motivation	They were very clear that simply they don't have any motivation, any reason that they can see to do DfRem. It's just not on their radar.	As before.	NONE	NONE
Knowledge and Understanding	They did not feel that this was a big issue for them.	There was a little confusion, but generally designers seemed fairly knowledgeable considering they are not expected to carry it out.	NONE	NONE
Management Commitment	Managers did say that they had an interest in the overall performance of the company, but it was still very low on their priorities.	Brief mention that managers could do more to promote DfRem, that doing DfRem depended upon management requesting it of them.	NONE	NONE
OEM-Reman Communication	Could not see very much benefit in communication.	NONE	Could see the benefit in the two business units working more closely together, cited as a main area for improvement.	Feel communication is fine as it is- good to have little, but not a particular problem.
Organisational Structure	They said changes to company structure have distanced the two parties, and also felt that they were in some ways competing with aftermarket.	NONE	Gave the same reasons as design management.	They disagree that the business model leads to competition between the two parties.
Design Reviews	Cited as a time when reman MAY be brought up in front of designers.	NONE	NONE	NONE
Design Tools	NONE	NONE	NONE	NONE
PDS	Briefly mentioned that the PDS is full of demanding customer requirements, leaving little room for DfRem.	NONE	NONE	NONE
Priorities	Reman is barely even on the priority list due to lack of customer demand or interest.	Same as before.	NONE	NONE
Reman Commitment	NONE	NONE	NONE	NONE

Company C

EXTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management
Customer demand	They were unsure, and doubtful about customer demand.	NONE	Unsure about demand specifically for reman, but they are aware that customer demand for service packages is very important.
Profitability	NONE (UNKNOWN) They basically don't know yet if it would be profitable, and there are concerns about the size of the company regarding this.	NONE	NONE (UNKNOWN) As before.
Environmental Impact	They don't feel their customers are interested in sustainability	NONE	They do sometimes get inquiries about sustainability, but it is not a serious issue for them at the moment, beyond legislation.
Suitable Products	This is the main reason why management are interested in my research, they are aware that others are making money from similar products.	NONE	As before.
Supplier Relationship	Mention that some of the most remanufacturable parts come from suppliers.	NONE	As before.
Engineering Resources	Concerns that the company are too small to do reman profitably.	Concerns the design team is too small to find time for DfRem.	Same as design engineers.

INTERNAL FACTOR	Design Management	Design Engineers	Aftermarket Management
Designer Motivation	As long as there is no reman, they are simply not motivated to do it, as much as they can see the potential benefits if and when.	As before, only even stronger as they aren't even aware of any plans to move to reman.	Same as design management.
Knowledge and Understanding	They are conscious of the fact that they need more knowledge and information on reman and DfRem.	Have some awareness of reman, and feel they could carry out DfRem with a little guidance.	NONE
Management Commitment	Basically everything upon TOP management making the initial decisions before anything like DfRem will follow.	NONE	As before.
OEM-Reman Communication	NONE	NONE	NONE
Organisational Structure	NONE	NONE	NONE
Design Reviews	NONE	The closest thing to DfRem is their serviceability audit.	NONE
Design Tools	NONE	NONE	NONE
PDS	NONE	NONE	NONE
Priorities	Simply not a priority.	NONE	NONE
Reman Commitment	NONE	NONE	NONE

Appendix 3: Publications

3A: List of Journal publications

G.D. Hatcher, W.L. Ijomah, J.F.C. Windmill

Design for remanufacture: a literature review and future research needs

Journal of Cleaner Production, Volume 19, Issues 17–18, November–December 2011, Pages 2004–2014

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

Integrating design for remanufacture into the design process: the operational factors

Journal of Cleaner Production, Volume 39, January 2013, Pages 200–208

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

Design for the Remanufacturing in China: a Case Study of Electrical and Electronic Equipment

Journal of Remanufacturing, Volume 3, No.3, March 2013

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

A Network Model to Assist 'Design for Remanufacture' Integration into the Design Process

Journal of Cleaner Production, In Press, September 2013.

3B: List of Conference papers

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

Design for Remanufacture in an OEM-Remanufacturer Organisation

International Conference on Remanufacture

University of Strathclyde, Glasgow. July 28, 2011

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

Integration of Remanufacturing Issues into the Design Process

Proceedings of the 18th International Conference on Engineering Design (ICED11), Vol. 5

Technical University of Denmark, Copenhagen. August 15, 2011

G.D. Hatcher , W.L. Ijomah , J.F.C. Windmill

Design for Remanufacture: Organisational Factors Influencing Successful Integration into the Design Process

Design for Innovative Value Towards a Sustainable Society Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing

TERRSA, Kyoto. December 1, 2011

Appendix 4: Artwork

Comic print produced for an exhibition at Scotland House, Brussels, in 2012. The theme of the exhibition was ‘energy and climate change’ and was organised by Creative Scotland and the Dundee Contemporary Art Centre. The piece is currently on display at the Centre for Comic Studies, Dundee University.