Closed-Loop Supply Chain Management and Remanufacturing in the Automotive Sector

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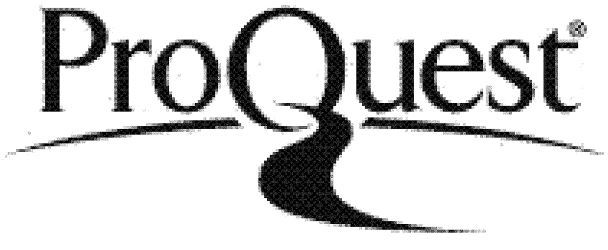
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Abstract

The increasing global awareness of environmental issues has led to corresponding initiatives across all industry sectors. These initiatives are claimed to be motivated by legislation, consumer pressure or corporate social responsibility. This thesis investigates product recovery and closed-loop supply chain management in the automotive sector, with a particular emphasis on remanufacturing.

The thesis takes an interdisciplinary point of view. On the one hand, it addresses remanufacturing in the automotive sector from a supply chain perspective; on the other hand, this work was influenced by the main debates in the environmental social sciences. As a result, the research problem consists of two parts:

The first part asks for the appropriate closed-loop supply chain and remanufacturing structures with regard to the automotive sector. Since closed-loop supply chain management is still considered as a new and emerging discipline, existing closed-loop supply chain models are reviewed and assessed with regard to their applicability to the automotive sector. Two in-depth case studies within the facilities of Original Equipment Manufacturers investigate the remanufacturing process for passenger car engines and electronic devices. The conceptual models of two specific closed-loop supply chains for automotive remanufacturing are developed. Furthermore, a new terminological framework is generated for closed-loop supply chain management, influenced by industrial ecology theory and systems thinking.

The second part of the research problem questions the 'classic' rationale behind product recovery. It seeks to identify the reasons for the establishment and management of product recovery operations, such as remanufacturing. Within this research, the classic assumptions of corporate social responsibility, product take-back legislation and profitability are examined with regard to their applicability to the automotive sector. The research findings demonstrate that the 'classic' motives are not valid for the two specific case studies. An entirely new set of motives is presented and discussed. Thereafter, the case study findings are tested and verified within a broader automotive remanufacturing context, including subcontracted and independent remanufacturers. The testing and verifying of the case study results is undertaken through a questionnaire survey.

The results of this research make three distinct contributions. The first contribution refers to the immediate body of knowledge on closed-loop supply chain management. The thesis reviews existing closed-loop supply chain and remanufacturing structures and creates, through the application of the research findings, new and more appropriate structures for the automotive sector. Secondly, the findings contribute to the development of a theory for closed-loop supply chain management. They demonstrate that theories from related fields cannot sufficiently explain why corporations engage in product recovery activities. This thesis therefore develops a rationale for closed-loop supply chain management and remanufacturing in the automotive sector. The third contribution is made with regard to methodology. Research in closed-loop supply chain management has been largely dominated by quantitative contributions. This thesis therefore adds to methodology by taking an interdisciplinary perspective and by applying a unique combination of methodological considerations to investigate the specific research problem.

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Chapter One
Introduction and Problem Definition

1.1 Introduction

The increasing global awareness of environmental problems and the creation of a 'global agenda for change', The Brundtland Report (World Commission on Environment and Development, 1987), has affected industries worldwide. The automotive industry, as one of the largest and economically most significant industry sectors, has been influenced by a variety of international, national and local constraints. These measures have an impact on automobiles at all stages of the life cycle: manufacturing, use and end-of-life. Moreover, the responsibility for end-of-life products is, in many countries and industry sectors, no longer the responsibility of the consumers or end-users, but has been transferred to the producers.

As a result, the significance of product recovery activities has increased in various industry sectors. Since environmental programs are often perceived as unprofitable, it is often claimed that legislation is to date the major motivation to the implementation of environmental measures. However, as the product recovery industry progresses, more

and more researchers perceive the combination of a response to legislative pressure and the promotion of corporate social responsibility as economically and environmentally beneficial (e.g. Linton, 1999; Klausner and Hendrickson, 2000).

This chapter provides an introduction to this thesis. The illustration of the research problem and the research questions in Section 1.2 gives the first insights into the area of end-of-life product recovery management. This field of research has often been described as so immature that it is not even entirely understood by experts (Goggin and Browne, 2000). The immaturity of the discipline of closed-loop supply chain management cannot only be confirmed from a corporate management perspective, but also from a scientific point of view, as this chapter will demonstrate.

The remaining sections of Chapter One outline why this specific research is valuable to the field of study (Section 1.3) and give an overview of the thesis' layout (Section 1.4).

1.2 Research Problem and Research Questions

This chapter outlines the research problem for this thesis. The research problem is split into two parts. The first part of the research problem seeks to identify the appropriate closed-loop supply chain and remanufacturing structure for the automotive industry. The second part investigates the rationale behind closed-loop supply chain management and product recovery. The final research problem does not represent the initial starting-point of the research. Chapter Four will explain in detail how the literature and previous contributions have led to an initial problem formulation for this research. Chapter Four also outlines how the direction of the research has changed due to a continuous interplay between data collection and analysis. The overall direction of the research was therefore gradually adjusted and revised over time. This section, however, will only outline the final research problem.

Automotive Closed-Loop Supply Chain Structures

In the course of the literature review, the author discovered that previous contributions within the area of reverse logistics and closed-loop supply chain management tended to

generalise within their closed-loop supply chain structures. These generalisations concerned the reasons for product returns, types of product returns, players involved as well as types of product recovery operations. After the first case study, it was found that previous closed-loop supply chain models were too generic (e.g. Thierry *et al.*, 1995), but it was also unclear whether existing models were applicable to the automotive industry. Research Question 1 therefore aimed at the development of a real-world closed-loop supply chain model for the automotive sector (Chapter Two). Since there was a need to delineate the scope of the study, a specific emphasis was put on the closed-loop supply chain for automotive remanufacturing.

The generalisation of previous models may have been partly based on the fact that the overall area of closed-loop supply chain management was, at the time of the research, still perceived as a rather novel discipline. However, in the course of the research, various contributors have discovered the need for more specific closed-loop supply chain structures. With regard to reverse logistics, De Brito *et al.* (2003a), for example, have outlined that generalisations should not be made, since subtle differences between reverse flows may shape the reverse logistics process or the closed-loop supply chain. These differences include the diversity of actors (e.g. government, retailers, manufacturers), return reasons (e.g. manufacturing returns, distribution returns, customer returns), or motives for product returns (e.g. economics, legislation, corporate citizenship). In the course of this research, the field has therefore developed from generic observations (e.g. Thierry *et al.*, 1995) to very specific closed-loop supply chain models (e.g. Guide and Van Wassenhove, 2003a). This fact not only supports the direction of this research, since other contributors have perceived the same needs for research, but also leads to the assumption that the overall field of closed-loop supply chain management will become more and more fragmented. In fact, various 'islands' of research have developed within the area, for example closed-loop supply chain management for commercial returns (e.g. Blackburn *et al.*, 2004; Tibben-Lembke, 2004), packaging take-back (e.g. Matthews, 2004), for recycling and re-use (e.g. Geyer and Jackson, 2004) and for remanufacturing (e.g. Seitz and Peattie, 2004). The first research question was therefore phrased as:

Research Question 1:

Which existing closed-loop supply chain structures are relevant to the automotive industry?

This research not solely aimed to develop a closed-loop supply chain structure for the automotive sector, but also sought to investigate the actual recovery process (remanufacturing) in more detail. Although remanufacturing is not new to the automotive sector, or the scientific debate of product take-back and recovery, Daniel Guide, a major contributor in the field of remanufacturing has confirmed that most research associated with remanufacturing is quantitative, such as the mathematical representation of production planning strategies (Guide, 2000). Guide has furthermore explained that a very limited number of empirical case studies exist. Existing case studies tend to be limited to a specific functional activity, for example scheduling (Guide, 2000). Hence, there was the need for holistic, empirical research within a specific industrial setting. "There are numerous areas for research in production planning and control for remanufacturing. One of the major weaknesses of previous research is that little has been done to document present industry practice in case studies or surveys" (Guide *et al.*, 1999, p.229). Research Question 2 therefore aims to examine existing remanufacturing process structures and thereafter the research seeks to develop a process structure for automotive remanufacturing.

Research Question 2:

Which existing remanufacturing process structures are relevant to the automotive industry?

Identification of a Rationale for Automotive Remanufacturing

The second part of the research problem aims to test the validity of the 'classic' rationale behind product recovery for automotive remanufacturing. While the focus on

car engine and electronic device remanufacturing is justified and illustrated in Chapter Four, this section is limited to the development of the three further research questions.

The necessity to identify the motives for remanufacturing began to unfold when, during the first case study visit, profitability was questioned as one of the main motives for automotive remanufacturing. Due to the review of literature, there has been the presumption that the automotive engine, as the most expensive part in the car, is the most profitable aggregate to recover and that therefore the overall remanufacturing process is profitable. However, this motive was called into question by the initial research findings. Further reasons for product recovery, which had not been challenged by previous researchers, were questioned with regard to their validity within the automotive sector. As a result, three further research questions were created. Each of these questions was extracted from the literature and asked whether a specific motive is applicable to automotive remanufacturing. Research Question 3 examines ethical and moral responsibility as a reason for automotive remanufacturing.

Research Question 3:

Is automotive remanufacturing induced by the corporation's needs to be morally or ethically responsible for its actions?

This research question was taken from the literature on corporate social responsibility and the theory of industrial ecology. Industrial ecology theory assumes that humanity seeks to maintain (deliberately and rationally) a 'desirable carrying capacity' (Allenby, 1999). The concept of corporate social responsibility adds that a company is (morally or ethically) responsible for the impacts of its actions (e.g. French, 1990; Klonoski, 1991). Also, contributors from the fields of closed-loop supply chain management and reverse logistics have outlined the role of 'corporate citizenship' as motive for product take-back (e.g. De Brito *et al.*, 2003). As the main reasons for being social responsible, contributors have listed 'green consumerism', the 'green marketplace' (e.g. Elkington, 1994) and competition (e.g. Burke and Logsdon, 1996). Literature on reverse logistics and product recovery has also noted the commitment to environmental issues, ethics, as

well as producer responsibility as reasons for undertaking reverse logistics and product recovery (e.g. Kopicki *et al.*, 1993; Fleischmann *et al.*, 1997; Carter and Ellram, 1998; Dowlatshahi, 2000; Ferrer and Whybark, 2000; Fleischmann *et al.*, 2000; Klausner and Hendrickson, 2000). These assumptions are therefore tested within this research. The main objective is to discover if these assumptions are valid for the automotive remanufacturing sector.

Research Question 4:

Is automotive remanufacturing induced by product take-back and recovery legislation, such as the European End-of-Life Vehicle Directive?

Research Question 4 was developed from the review of literature within product recovery management and related fields of research. There has been an extensive discussion with regard to end-of-life take-back strategies (e.g. Toffel, 2003), compliances with governmental regulations (e.g. Bansal and Roth, 2000), pre-empting legislation (e.g. Toffel, 2004) or transforming regulative pressures into a competitive advantage (e.g. Den Hond, 1996; Handfield *et al.*, 1997). However, Research Question 4 investigates, whether there is a relationship between environmental regulations and product recovery operations, which many contributors have assumed as a given fact (e.g. Cairncross, 1992; Lamming and Hampson, 1996; Nagel and Meyer, 1999; Guide, 2000; Linton, J.D., 2000; Guide and Van Wassenhove, 2002b; Toffel, 2003; De Brito *et al.*, 2003a). This research will investigate whether automotive remanufacturing is undertaken as a result of product take-back and recovery legislation.

Research Question 5:

Is automotive remanufacturing induced by direct economic motives (i.e. profitability of remanufacturing)?

The profitability of reverse logistics, product recovery and other so-called 'green' activities, has been questioned by various researchers (e.g. Westkämper *et al.*, 1999; Klausner and Hendrickson, 2000). Although there have been supporters of the

assumption that product recovery operations are profitable (e.g. Andel, 1997; Linton, J., 1999; Schendler, 2002), the 'economics of win-win' has also been an ongoing debate within industrial ecology theory (e.g. Ayres and Ayres, 1996). Hence, the assumption emerged that closed-loop supply chains create economic and environmental benefits (e.g. Geyer and Jackson, 2004), although others claim that the question of profitability was often presupposed and perceived as 'obvious'. Yet, the question of profitability has not been adequately addressed by previous research (Guide *et al.*, 2003b). This research does not to provide a detailed economic and environmental assessment of the operations as often applied by industrial ecologists (e.g. Frankl, 2001; Geyer and Jackson, 2004). It will rather seek to find an answer to this question through a qualitative approach. Research Question 5 will therefore investigate whether a direct economic motive (i.e. profitability or remanufacturing) is the reason for Original Equipment Manufacturers (OEMs) to undertake remanufacturing of automotive parts and components.

Aims and Objectives of the Research

This dissertation has four aims. Firstly, it intends to complement and extend the immediate scientific fields of closed-loop supply chain and product recovery management. Secondly, it aims to make a contribution towards a theoretical framework for closed-loop supply chain management. At the same time it seeks to contribute to theories of related fields, such as industrial ecology theory or systems thinking. Thirdly, this research intends to make a methodological contribution. The final objective this research seeks to meet is to provide elements that inform future research in the areas of closed-loop supply chain management and remanufacturing, as well as to develop ideas and implications for the automotive remanufacturing sector. All aims and objectives are briefly outlined in the following.

Chapter Two will demonstrate that the scientific field of closed-loop supply chain and product recovery management is still relatively new. There has been a large body of literature on reverse logistics, which is seen as an element of the closed-loop supply chain and whose awareness amongst academics has grown since the early 1990s. Although there have been previous contributions on individual elements of the closed-

loop supply chain, the holistic concept of closed-loop supply chain management, which involves the combination of product acquisition, reverse logistics, testing, sorting, disposition, recovery and distribution (e.g. Guide and Van Wassenhove, 2003b), has only gained attention in the late 1990s. As a result, this research seeks to complement and extend the field by a specific contribution on automotive closed-loop supply chain management.

The lack of a grounded theory for environmental management, reverse logistics and closed-loop supply chain management has been confirmed by various researchers in the field (e.g. Handfield *et al.*, 1997; Van Hoek, 1999). One of the reasons for the lack of an appropriate theory for research in this field is the fact that the discipline of closed-loop supply chain management is very new. "Because the academic research focus on these environmental issues is relatively new, little prior theory exists in which to ground testable hypotheses concerning the role of environmental management in the operations management value chain" (Handfield *et al.*, 1997, p.294). The lack of an appropriate theory will be discussed in Chapter Three. The appropriate research methodology for theory-building in this area will be developed in Chapter Four. The research outcome is therefore expected to provide the first elements of a theory for closed-loop supply chain management and to provide new insights for theories in related fields, such as industrial ecology theory and systems thinking.

Since the discipline of closed-loop supply chain management is perceived as underdeveloped, this research intends to make a methodological contribution through a unique approach to research. The approach comprises the application of inductive thinking and grounded theory to an in-depth, holistic and multiple case study research. This combination of methodological considerations can be recognised as novel, since much of the previous research in the area has been based on quantitative studies with regard to individual elements of the closed-loop supply chain (e.g. Ferrer, 1997b; Guide and Srivastava, 1997; Fleischmann *et al.*, 2000). The second methodological contribution is sought to be made by the combination of an in-depth understanding of the business perspective (closed-loop supply chain management) and an investigation of the environmental perspective (e.g. industrial ecology; sustainability). In other words,

by taking an interdisciplinary perspective, this new methodological approach may provide insights which have not been discovered by previous research in which a different perspective was taken.

The fourth aim of the research refers to the industrial implications the research findings seek to provide. On the one hand, the research aims to identify aspects which could improve remanufacturing operations in the automotive sector and the automotive closed-loop supply chain. On the other hand, the research seeks to provide findings which can support the management of remanufacturing operations and closed-loop supply chains in other industries. Moreover, there may be implications arising from this research, which could lead to an interaction between the remanufacturing sector and scientific research. This research therefore aims to unravel starting-points for future research which are also relevant within the remanufacturing sector. It is therefore sought to identify and document shortcomings within the field, which cannot be dealt with in this thesis, but may represent ideas for future scientific research.

1.3 Justification for the Research

This section aims to provide the justification for this research. It firstly identifies why the research problem is worth being studied from a scientific perspective. Thereafter, justifications are made with regard to a theoretical, a methodological and an industrial point of view.

Chapter Two will demonstrate that it may be assumed that the field of closed-loop supply chain management has developed from reverse logistics. Although the area of reverse logistics provides an excellent framework for the development of closed-loop supply chain networks, existing research has neglected to describe "[...] an in-depth understanding of the complexity of the factors affecting the reverse logistics activities [...]" (Knemeyer *et al.*, 2002, p.456). This complexity also refers to the limited applicability of theoretical research in the field, which has led to a discrepancy between scientific research and industry practice. Several key contributors have expressed the need for a link between theoretical research and the 'real-world'. With regard to

inventory control for product recovery, Van der Laan *et al.* (2003) have admitted a limited applicability of current models, which have produced interest in academia, but have lacked importance in the industrial sector: "[...] at least the scientific community believes that this field is worth studying" (p.219). As a result, Van der Laan *et al.* (2003) recommend that research should focus on case studies in order to bridge the gap between academic research and practice. Guide *et al.* (1999) confirm that concerning research on remanufacturing, previous research has neglected to present real-world industry practice through case study or survey research. Hence it is assumed that the investigation of real-world remanufacturing case studies will bring benefits to the scientific community by bridging the gap between theory and practice as well as by demonstrating the complexity of closed-loop supply chains. The research findings therefore aim at presenting a more specific basis for future scientific research, but also seek to provide benefits to the (automotive) remanufacturing industry.

Chapter Three reviews theories and concepts from related fields in order to identify the appropriate theoretical framework for this research. Van Hoek (1999) argues that contributions within environmental operations management, which often focus on the area of reverse logistics, have failed to develop a grounded theory or a theoretical framework for the application of these approaches. Giuntini (1996) adds that this may be due to the fact that research on reverse logistics, for example, is still at an introductory stage of the life cycle and will take at least ten to fifteen years until this type of logistics becomes a standardised part of supply chains. Closed-loop supply chain management research, which is assumed to have developed from reverse logistics research, is even less grounded in theory. Van Hoek (1999) therefore concludes that there are two needs for further research: Firstly, future research needs to go beyond the limited perspective of reverse logistics by applying a holistic view which includes the entire (green) supply chain rather than elements of the supply chain (e.g. reverse logistics) only. Secondly, research needs to embrace the development of a theoretical framework for research on 'green supply chains' (Van Hoek, 1999). As it will become clear, no existing theory which could entirely support this research was found. The author therefore decided to aim for the development of the first elements for an initial, rudimentary, theoretical statement for closed-loop supply chain management.

A further justification for the relevance of this research from a theoretical perspective is the discovery that was made in the initial stages of the research. Within the first case study, it was found that due to the lack of a theoretical framework, research in the field has been based on assumptions which could not be applied to this research. These assumptions referred to the motives for product recovery, but also to the validity of existing closed-loop supply chain structures. Chapters Two, Three and Four elaborate on these aspects in more detail. However, the discrepancy between what previous contributors have claimed and what industry practice has shown, have confirmed the needs for this research.

There were two main factors which have shaped the methodological considerations for this research and therefore supported the needs for this type of research from a methodological point of view. Firstly, since the need for the development of an appropriate theory for closed-loop supply chain management was discovered, a unique combination of research strategy and data collection methods had to be developed in order to meet the requirements of the theory-building process, which previous research has failed to address. Chapters Three and Four demonstrate that within the theory-building process, different methodological approaches were required as opposed to those that were applied by previous research in this field. Although it may be argued that research on closed-loop supply chain management is less developed and that there is the need for the development of a theory for this discipline, previous contributions have aimed at the optimisation of individual aspects (see Section 2.5.5) by applying tools and techniques, which Whetten (1989) as well as Handfield and Melnyk (1998) have recommended for theory refinement and extension, rather than theory development.

Secondly, Chapter Four will outline in more detail that relevant research in the field of remanufacturing has often taken a broader view by examining a variety of industries (e.g. Guide, 2000; Guide and Van Wassenhove, 2003c; Hauser and Lund, 2003). Those who have focused on the automotive sector have applied different main data collection methods, such as questionnaire surveys (e.g. Hammond *et al.*, 1998) or mathematical modelling (e.g. Van der Laan, 1997; Langella, 2003). Hence, this research is justified through the provision of a unique methodological combination which puts an in-depth

focus on remanufacturing operations, but likewise emphasises the whole context of closed-loop supply chain management.

In addition, previous research has largely applied deductive thinking to research. The deductive approach to research has often led to a narrow focus on the local optimisation of specific operational issues, which has already been criticised by Guide *et al.* (2003b). This may be due to the fact that most of the contributors in the field originate from a background with solid modelling skills, as De Brito *et al.* (2003b) have noted. As a result, this research is justified from a methodological perspective, since there is the need to uncover whether a new set of methodological considerations results in the same findings than previous research studies which have applied different methodologies.

At the beginning of this section, it was outlined that the link between scientific research on closed-loop supply chain management and the product recovery industry is still underdeveloped. As a result, more empirical research is needed to reduce the gap between the two elements. Hence, from an industrial perspective, this research is beneficial since it may uncover starting-points for improvements which can be either addressed directly or further developed within the scientific community and then implemented in practice. Guide emphasises the mutual benefits of such a strategy. "Future research must be grounded with industrial data to ensure that it is relevant to actual concerns" (Guide *et al.*, 1999, p.229).

Moreover, this research not only seeks to feed back to the remanufacturing sector, but may provide new insights for the automotive sector and for further industries in which closed-loop supply chains play a role. On the one hand, the documentation of the automotive closed-loop supply chain and the provision of in-depth process data may outline pitfalls which other industries should avoid or best practice that can be copied. On the other hand, the understanding of the 'background' to closed-loop supply chain management, such as the identification of the motives behind product recovery operations, may assist in predicting ecologically-based behaviour, as already outlined by Bansal and Roth (2000).

1.4 Chapter Outline

The layout of this dissertation follows a style which has been termed as the 'hour glass notion of research' by Trochim (2003). This means that the thesis firstly takes a broad and general perspective by elaborating on the wider research environment in Chapters Two and Three. The in-depth case studies (Chapters Six and Seven) tighten the scope of the research by investigating the specific research questions. Thereafter, the scope is broadened when the specific findings from the case studies are tested through a questionnaire survey in a broader research environment. The results of the questionnaire survey are discussed in Chapter Eight. Chapters Nine and Ten further generalise the results of this research. The dissertation is concluded in Chapter Eleven. The contents of each chapter are briefly discussed in this section.

Chapters Two and Three aim at embedding this research into the scientific research context. In Chapter Two, the first two research questions are developed. The chapter firstly provides a scientific framework for research in product recovery management. Closed-loop supply chain management is thereby perceived as a relatively new area of research. As a result, key definitions and terms are defined and applied to the automotive sector. In addition, shortcomings within the field of closed-loop supply chain management are outlined. A further purpose of Chapter Two is to place this dissertation into the scientific context, whereby a particular emphasis is put on closed-loop supply chain management and remanufacturing as a recovery operation.

Chapter Three has two aims. On the one hand, it seeks to demonstrate that there is a lack of theoretical grounding for research in closed-loop supply chain management. It therefore justifies the needs for finding and developing an appropriate theory for closed-loop supply chain management. Secondly, through the review and discussion of theories and concepts from related fields, this chapter aims to identify elements, which could provide the first steps for building a theory for closed-loop supply chain management. In order to achieve this objective, Chapter Three develops three further research questions, which comprise explanations for the rationale behind product recovery. These explanations, which have been taken from the literature, are tested with regard to their validity in the automotive sector.

Chapter Four, which reviews, selects and discusses research methodology, is a central element of this thesis. There are several reasons for this. Firstly, the chapter represents the link between the research problem (research questions) and the empirical research. Secondly, this chapter reviews the appropriate methodology which will be applied to this research. It therefore justifies why the selected research strategy and data collection methods have been perceived as the most suitable for this research. Thirdly, the chapter presents the overall line of enquiry and how it has developed in the course of the research. The research initially started from a broader base and has become more specific over time. In addition, the combination of the two approaches, 'grounded theory' and 'exploratory research', has demanded changes to the direction of the research. Chapter Four therefore presents and explains why and how these changes have occurred and how they are justified. The chapter concludes with a discussion on the overall validity of the research.

Chapter Five gives an account of the automotive supply chain and the aftermarket. The chapter plays an introductory role to the empirical research which follows in Chapters Six, Seven and Eight. Chapter Five contains background research on the players within the automotive supply chain, their relationships and the aftermarket distribution structure. The second part of this chapter focuses on the European remanufacturing sector. It also introduces the two product groups which are most relevant to this dissertation, passenger car engines and electronic devices. The chapter hereby outlines characteristics of engine manufacturing and electronic device production practices in order to provide the foundation for the subsequent chapters. As a result, Chapter Five embeds this dissertation into an industrial context which complements its incorporation into the scientific and theoretical context, as achieved by Chapters Two and Three.

The first empirical chapter, Chapter Six, presents and discusses the results from the first in-depth case study on OEM engine remanufacturing. It characterises engine remanufacturing and outlines the typical remanufacturing process of engines. By developing a specific closed-loop supply chain remanufacturing process structure, it also provides the first steps for answering Research Questions 1 and 2 with regard to engines. Moreover, obstacles within the process of engine remanufacturing are

identified and discussed. In this way, the chapter represents a connecting piece between the research questions and the discussion of results which follows in Chapters Nine and Ten.

Chapters Seven and Eight follow the demands of 'grounded theory' with regard to the change of direction which occurred after revisiting the research questions. As a result of the interplay between data analysis and data collection from the first case study research (Chapter Six), new and more relevant research needs are identified. This has led to an investigation of OEM electronic device remanufacturing (Chapter Seven) and the implementation of a questionnaire survey (Chapter Eight). These two chapters also link the research questions with the discussion of the research findings in Chapters Nine and Ten.

Chapter Nine defines and develops key definitions and theoretical models for closed-loop supply chain management. It thereby links the first two research questions which are developed in Chapter Two with what has been found within this research. As a result, new insights on 'real-world' remanufacturing issues are generated which may provide more detailed starting-points and assumptions for future research. The results discussed in Chapter Nine present a new terminological framework for closed-loop supply chain management. This framework is applied to the automotive industry and two industry-specific closed-loop supply chain structures are presented and discussed. Chapter Nine also develops a new set of issues and obstacles that may be considered within future scientific research.

Chapter Ten relates the three research questions which were identified in Chapter Three to the presentation of results in Chapters Six to Eight. Chapter Ten questions the validity of explanations for closed-loop supply chain and product recovery management that are proposed by existing theories, concepts and the literature. It hereby firstly aligns findings and assumptions of previous research with the findings from this research. The assumptions include ethical and moral responsibility, product take-back and recovery legislation as well as a direct economic motive as main reasons for closed-loop supply

chain management and remanufacturing. These assumptions are declined for OEM automotive remanufacturing. Instead, Chapter Ten presents a variety of motives, which have been discovered by this research.

Chapter Eleven concludes the thesis. It firstly summarises what this dissertation has investigated and what has been omitted. It hereby justifies why and how these delineations were made. Secondly, the aims and objectives of the research are subsumed. The chapter also discusses to what extent research objectives might be fulfilled with regard to a contribution to the related and immediate fields of knowledge. Furthermore, the contribution to theory and the methodological contribution are outlined. The chapter concludes with a discussion on how this research may inform future research in the field and what implications for industry may be drawn from the research. Hence, the needs of future scientific research and suggestions for industry are proposed.

Figure 1 summarises the overall outline of the dissertation, the relevance of each chapter and how the chapters are linked to each other.

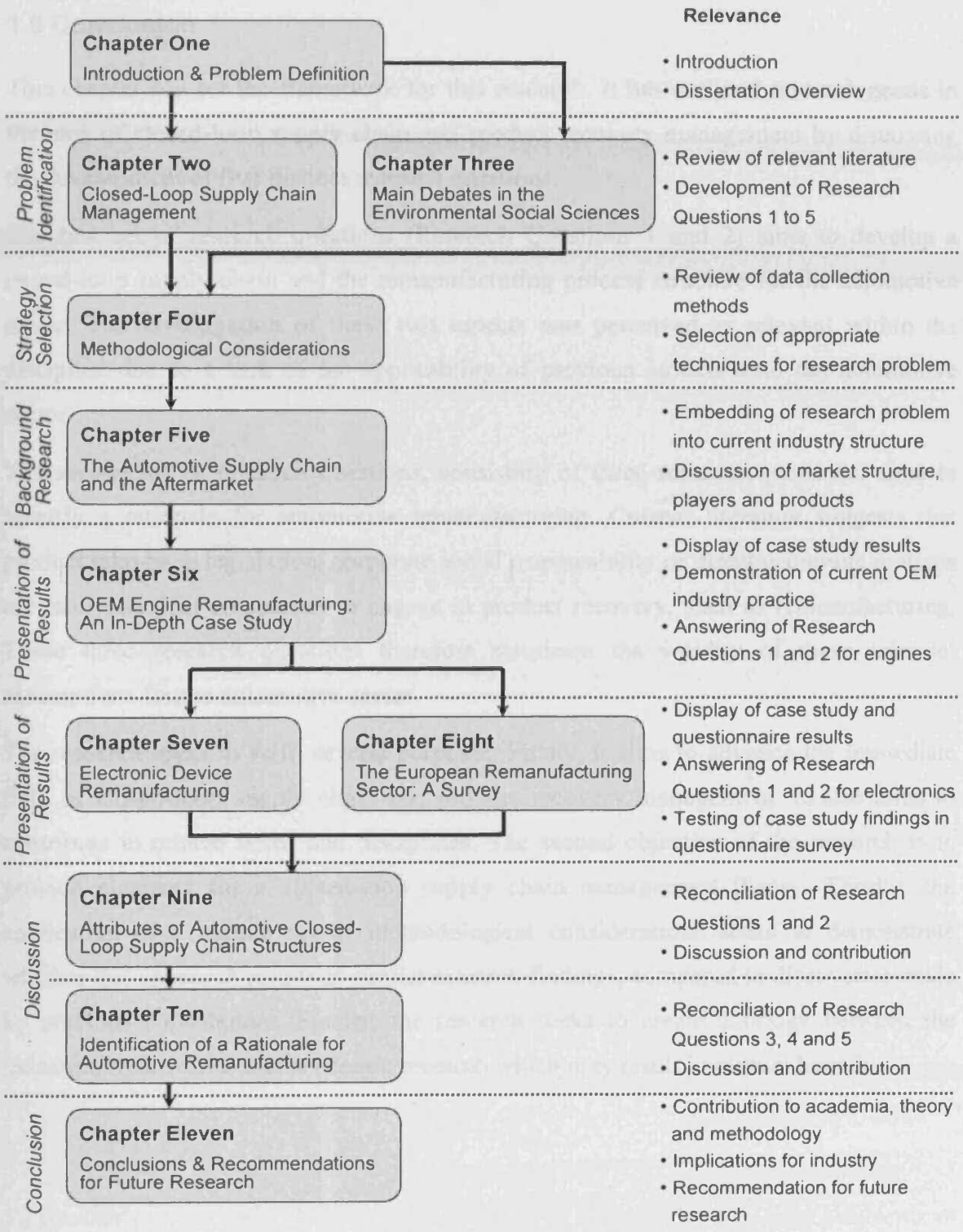


Figure 1: Thesis Layout and Overview

1.5 Conclusion

This chapter has set the framework for this research. It has outlined research needs in the area of closed-loop supply chain and product recovery management by discussing the development of five distinct research questions.

The first set of research questions (Research Questions 1 and 2) aims to develop a closed-loop supply chain and the remanufacturing process structure for the automotive sector. The investigation of these two aspects was perceived as relevant within the discipline due to a lack of the applicability of previous models onto the automotive sector.

The second set of research questions, consisting of three separate questions, aims to identify a rationale for automotive remanufacturing. Current literature suggests that product take-back legislation, corporate social responsibility or direct economic motives are motivators for companies to engage in product recovery, such as remanufacturing. These three research questions therefore scrutinise the validity of these 'classic' assumptions for the automotive sector.

The research seeks to fulfil several purposes. Firstly, it aims to advance the immediate field of closed-loop supply chain and product recovery management. It also aims to contribute to related fields and disciplines. The second objective of the research is to provide elements for a closed-loop supply chain management theory. Thirdly, the application of a unique set of methodological considerations seeks to demonstrate whether this approach results in similar research findings, compared to discoveries made by previous contributors. Finally, the research seeks to create a bridge between the industrial 'real world' and academic research which may result in mutual benefits.

Chapter Two
Closed-Loop Supply Chain Management

2.1 Introduction

This chapter aims to provide the scientific framework on product recovery management. It is split into two parts. In the first part, a brief overview of key publications in the area of supply chain management will be given and an appropriate framework for this dissertation will be derived by consulting contributions from closed-loop supply chain management. Moreover, the role of reverse logistics will be discussed and the first two research questions will be developed from the research needs identified within the literature.

The second part of this chapter will present one of the product recovery operations, remanufacturing, in more detail. An overview of previous research in the field will be given and a particular emphasis will be put on the uncertainties within remanufacturing. Furthermore, the remanufacturing operation will be placed into context by a discussion on its history, the players in the automotive remanufacturing sector and the presentation of remanufacturing models.

In the course of this chapter, two main targets will be achieved. Firstly, key definitions will be identified in order to provide a basis for the overall understanding of the research. Secondly, two research questions will be developed from the literature, aiming at the identification of closed-loop supply chain and remanufacturing structures for engine and electronic device remanufacturing. An overview of the topics which are outlined in this chapter is given in Figure 2.

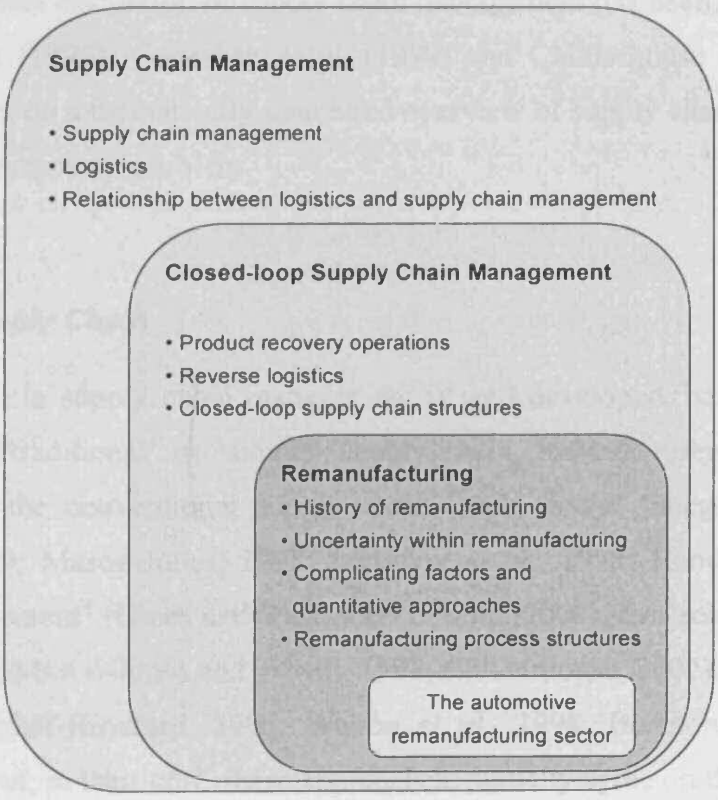


Figure 2: Chapter Overview

2.2 The Concept of Supply Chain Management

The growing interest in supply chain management has led to a significant amount of research and publications in this field. However, despite the interest in this body of knowledge, key definitions within this concept have been rather ambiguous (Ganeshan *et al.*, 1999). This section therefore focuses on the basics of supply chain management, in order to identify key definitions, such as supply chain (SC), supply chain management (SCM) or logistics. The relationship between logistics and supply chain management has also been discussed by Larson and Halldorsson (2004), for example.

Since a historical discussion of supply chain management has been undertaken by Prida and Gutierrez (1996), Ganeshan *et al.* (1999) and Childerhouse (2002), this section merely focuses on a thematically structured overview of supply chain literature which is relevant to the research problem.

2.2.1 The Supply Chain

Since research in supply chain management is well developed, hardly any contributor refers to the 'traditional' or 'simple' supply chain. Instead, research has focused on variations of the conventional supply chain, such as the 'integrated supply chain' (Stevens, 1989; Mason-Jones, 1998; McIntyre *et al.*, 1998; Handfield, 1999), 'value stream management' (Hines and Rich, 1997; Pullin, 2001), the 'seamless supply chain' (Towill, 1997; Mason-Jones and Towill, 1998; Childerhouse, 2002) or the 'green supply chain' (Bloemhof-Ruwaard, 1995; Walton *et al.*, 1998; Beamon, 1999; Van Hoek, 1999). However, in their core, these approaches mutually agree on the idea that a supply chain consists of a number of echelons (companies) within which material-, cash- and information flows circulate in order to ensure the supply of goods to the customer. Lambert *et al.* (1998b) define the supply chain as an alignment of companies, which brings products or services to the market. A simple, traditional supply chain is pictured in Figure 3.

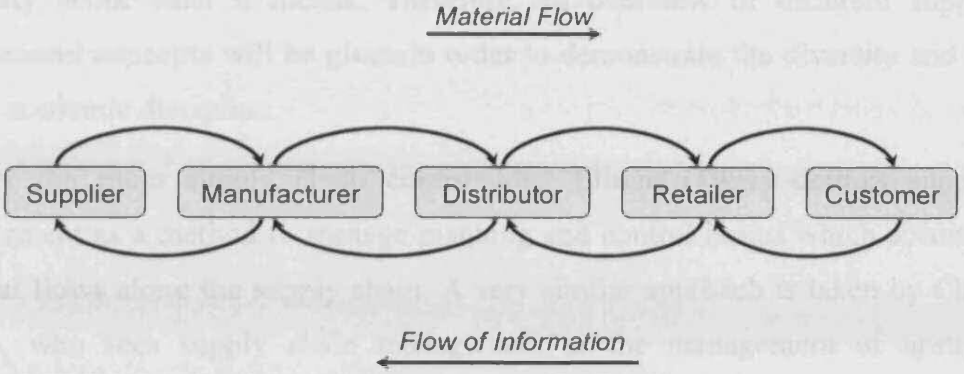


Figure 3: The Supply Chain

(Source: adapted from Jones and Riley, 1992, and Handfield and Nicholas, 1999)

Figure 3 shows a material flow from supplier to the customer and a flow of information in the other direction, as for example outlined by Stevens (1989):

> *The supply chain* [...] *is the connected series of activities which is concerned with planning, coordinating and controlling material, parts and finished goods from suppliers to the customer. It is concerned with two distinct flows through the organisation: material and information.*
>
> (Stevens, 1989, p.3)

This is confirmed by Mason-Jones and Towill (1999) who argue that, "all supply chains have two distinct and basic flows, known as the material pipeline and the information pipeline respectively" (p.14). However, this point of view is not shared by all contributors in the field. Some authors extend the range of flows along the supply chain, such as Naim (1997), who adds cash and resource flows to the understanding of the transactions within a supply chain.

2.2.2 Supply Chain Management

Due to the increasing amount of research and publications in this field, the understanding of supply chain management has becomes indistinct. This has also been stated by Lambert *et al.* (1998b), who claim that the use of the term supply chain management has grown significantly since the late 1980s, but there is considerable

obscurity about what it means. Therefore, an overview of different supply chain management concepts will be given in order to demonstrate the diversity and spectrum of this academic discipline.

One of the main supply chain contributors, Ellram (1991) defines supply chain management as a method to manage planning and control issues which accompany the material flows along the supply chain. A very similar approach is taken by Christopher (1998), who sees supply chain management as the management of upstream and downstream relationships with suppliers. He identifies one of the main goals within supply chain management as the delivery of superior customer value at less cost to the supply chain as a whole. Harland (1996) emphasises that supply chain management is a term that can be used manifold. It may, for example, refer to the 'internal supply chain', which integrates business functions from the inbound to the outbound flows, or to the management of a chain of companies.

However, since the term 'supply chain management' is widely used (Davis, 1993) and seems to have developed into a self-explanatory term in business, many authors seem to avoid specifying their understanding of supply chain management (e.g. Lamming and Hampson, 1996; Fisher, 1997). One prevailing approach in supply chain research is the 'integrated supply chain' (Stevens, 1989; Ellram, 1991; Bowersox and Closs, 1996; McIntyre *et al.*, 1998), which is the idea of focusing on a single integrated chain, rather than separated functional areas, in order to pursue the objectives of providing a high service level at low costs (Stevens, 1989). This perception of supply chain management will form the basis for this research. However, within this dissertation, the main focus of supply chain management lies on the totality and entirety of a supply chain, rather than the emphasis on high service levels or cost minimisation.

The delivery of the right products in the right quantity at the right time and at a competitive price has been identified as a universal objective within supply chain management (e.g. McIntyre, 1998; Shapiro, 2001). Moreover, there is the need to meet customer requirements and coordinate these with the material flows (Stevens, 1989; Ellram, 1991). This usually implies conflicting aims, such as high customer service, low inventory investment or low unit cost (Stevens, 1989). A more holistic view, pointed out by Lambert *et al.* (1998a), identifies the main objective of supply chain management as

maximising competitiveness and profit for each company, the whole supply chain network, as well as for the end-customer. However, this goal may not be achieved in all industries. Within the automotive sector, for example, the distribution of power among supply chain members defines the distribution of profits within the supply chain. This issue will be discussed in Chapter Five in more detail.

2.2.3 The Role of Logistics within the Supply Chain

According to Lambert *et al.* (1998b) and Ganeshan *et al.* (1999), supply chain management is an outcome of a progression from materials management and physical distribution via functional logistics to integrated logistics. The definition of logistics management principles evolved in the 1980s (Christopher, 1998). Since logistics and supply chain management are strongly linked, contributors tend to blend the borders between those terms.[1]

> *Logistics management* [...] *is the means whereby the needs of customers are satisfied through the coordination of the materials and information flows that extend from the marketplace, through the firm and its operations beyond that to suppliers.*
>
> (Christopher, 1998, p.13)

The definition by Christopher (1998) is very similar to the understanding of supply chain management as discussed in the previous section. Hence, there is the need for further clarification with regard to the role of logistics within supply chain management. Logistics, which was formerly just a name for physical distribution from the factory to the customer, has been extended by inventory management, planning and computer systems (Sharman, 1992). As a result, logistics is now defined as the link between an enterprise, its customers and its suppliers (Bowersox and Closs, 1996). In other words, logistics is the element that joins the supply chain echelons with each other. Supply chain management can therefore be seen as the super-ordinate concept of logistics. Logistics addresses the planning, implementation and control of the flows within the

[1] For an extensive discussion on the differences between logistics and supply chain management, please refer to Larson and Halldorson (2004).

supply chain (Lambert *et al.*, 1998a). Porter (1985) claims, that logistics, as a part of the value chain, plays a decisive role in company performance.[2]

Concluding, the key understanding of supply chain for this research can be summarised as the essential meaning of the integrated supply chain as defined by Stevens (1989), in which the emphasis is put on the integrated chain of companies (echelons) rather than on separate functional areas. Supply chain management therefore involves the management of relationships along the supply chain, whereas the planning, implementation and control of material, cash and information flows are seen as parts of logistics. As a result, logistics is an integral part of supply chain management. The author therefore adopts the 'unionist' perspective of the relationship between logistics and supply chain management, as termed by Larson and Halldorsson (2004).

[2] Porter (1985) defines the value chain as the entirety of activities a company performs in order to "design, produce, market, deliver, and support its products" (p.36). Christopher (1992) furthermore states that a firm has to promote value to its customers by performing these activities more efficiently than the firm's competitors, hence, creating greater value for the customer than the competitor.

2.3 Product Recovery Operations

The understanding of the diverse product recovery options is essential to the comprehension and the development of closed-loop supply chains. The discussion on product recovery operations has therefore to precede the debate on closed-loop supply chain management and reverse logistics.

Thierry *et al.* (1995) define product recovery management as the management of used and discarded products, components or materials within a manufacturing environment. They argue that the overall objective of product recovery management is the recovery of as much economic and ecological value as possible and simultaneously reducing as much waste as possible. Within this research, however, the author has decided to redefine this understanding of product recovery management as it seemed too broad for this thesis. The author therefore understands a product recovery operation as a process, which transforms an end-of-use or end-of-life product into a product of a clearly specified condition due to which it can be sold and/or utilised anew. This definition therefore excludes concepts such as incineration or waste disposal, which have been identified as product recovery operations by others. The author also excludes activities, such as cannibalisation, which some contributors (e.g. Thierry *et al.*, 1995; Bloemhof-Ruwaard *et al.*, 1995) have identified as product recovery operation despite the fact that no actual operation takes place. However, these types of operations are not relevant to this research. Product recovery management is therefore understood as the management of product recovery operations as defined by the author.

2.3.1 General Product Recovery Operations

In this section, an overview of general recovery operations will be given. These general operations will be specified for the automotive sector in the succeeding section in order to meet the demands of this research. A multiplicity of classifications with regard to product recovery operations exists and no consistent view seems to have gained ground, yet. This paragraph discusses the most common product recovery operations in the literature and results in a redefined compilation of definitions for this dissertation.

Horneber (1995) bases his classification of terminology on the distinction between two recovery goals, the retrieval of the 'work piece' or the retrieval of the material. In Horneber's point of view, the aim of recycling is to regain the material and utilising it for its initial or a different purpose. Giuntini and Andel (1995) further highlight Horneber's point of view by distinguishing between product life span and material life cycle extension.

Beamon (1999) on the other hand, describes recycling, re-use, and remanufacturing as part of the 'extended supply chain'. She defines recycling as the process whereby used products, components, and materials are collected, disassembled, and separated into categories. Afterwards, they are processed into recycled products, components, and materials. As opposed to this, re-use does not require any additional processing. The process of remanufacturing includes the collection of used products and the assessment of their condition. Worn, broken, or obsolete parts are replaced. "In this case, the identity and functionality of the original product is retained. The resulting (remanufactured) product is then inspected and tested, with the goal of meeting or exceeding the quality standards of brand new products" (Beamon, 1999, p.337). Thormark (2001) takes a different view by dividing the generic term recycling into three forms: re-use, material recycling, and combustion. He argues that re-use is a part of recycling and includes combustion in terms of energy recovery.

As a result, from a general perspective, it was found necessary to distinguish between product life-span extension and material life cycle extension, as for example pointed out by Giuntini and Andel (1995). Hence, the different product recovery operations can be subordinated to this main classification. Within this research, a distinction between remanufacturing, recycling, repair and re-use is made, as shown in Table 1.

Recovery Option	Explanation	Main Proponents
Remanufacturing	▪ Remanufacturing equals the transformation of used products into products with an as 'good as new' standard, while retaining their original identity. ▪ This option offers high value compared to recycling.	Ayres *et al.* (1997) Ferrer and Whybark (2000) Nagler (1999) Steinhilper (1998)
Repair	▪ Broken parts are replaced and the product is restored to 'working order'.	Giuntini and Andel (1995) Thierry *et al.* (1995)
Re-use	▪ Used products are resold with no additional processing required.	Beamon (1999) Browne and Zhang (1999)
Recycling	▪ Gaining base materials (e.g. plastics, metals) for use in the production of new parts and components.	Browne and Zhang (1999) Giuntini and Andel (1995) Thierry *et al.* (1995)

Table 1: General Product Recovery Operations

In the course of this research, De Brito and Dekker (2003a) have established a product recovery hierarchy, based on the waste hierarchy created by the European Community.[3] The framework proposed by De Brito and Dekker (2003a) is arranged in an inverted pyramid and sorted regarding product composition, ranging from what they call 'global' (e.g. re-sale, re-use or re-distribution) to specific levels (e.g. recycling, incineration or landfill). However, the author does not agree with this classification, since product recovery operations should be ranked with regard to the highest level of quality that can be achieved, rather than being classified by product characteristics.

Moreover, incineration, which contributors often see as a product recovery operation, is perceived as a part of waste disposal with negative environmental impacts (see Price, 1995; Smosarski, 1995; Horneber, 1995). Baran (2001) claims that "waste-disposal alternatives such as incineration and ocean dumping will no longer be acceptable with government regulations calling on product manufacturers to ensure the minimal environmental impact of their manufactured durable goods" (p.90).

[3] For this hierarchy, see, for example, Smosarski (1995).

Concluding, recovery options, such as 'reclaim' or 'thermal conversion' remain unconsidered within this particular research, since these aspects do not correspond with the author's understanding of a closed-loop system, which will be defined in Section 2.4.

2.3.2 Product Recovery Operations in the Automotive Sector

Since the general definitions of product recovery operations (Table 1) were not universally applicable to the automotive sector, it was necessary to create a new categorisation for the automotive industry. In 1984, Waters expressed that there is inconsistency with regard to product recovery terminology in the automotive sector. He therefore explained the differences between repair, rebuilt and remanufacturing. Hence, this section develops the key definitions of the major product recovery operations that occur in the automotive sector. These definitions are partly based on interviews and informal conversations within the fieldwork, but have also been developed from industry-specific literature whereby the framework suggested by Waters (1984) has been taken as the basis for Table 2.

Product recovery operation	***Recycling***
Quality level targeted	Various; in most cases 'downgrading'
Process description	▪ Extraction of base materials (e.g. glass, plastics, paper) ▪ Use of base materials in the production of new products
Place/location	Various
Return of identical product?	No

Product recovery operation	***Repair***
Quality level targeted	Working order
Process description	▪ Removal of defective parts ▪ Repair of these parts ▪ Reinstallation of the same parts
Place/location	▪ Anywhere ▪ Ranges from garage to hobbyist
Return of identical product?	Yes

Product recovery operation	***Reconditioning***
Quality level targeted	Arbitrary defined level
Process description	▪ Repair of defective parts ▪ Replacement of irreparable and worn-out parts with parts of unknown quality ▪ Quality tests may or may not take place
Place/location	Mainly performed by independent 'reconditioners'
Return of identical product?	Yes

Product recovery operation	***Factory Overhaul***
Quality level targeted	Standards and specifications meet quality gates for new products
Process description	▪ Repair of defective components ▪ Replacing of irreparable, aging or worn parts ▪ Extensive testing ensures perfect functioning
Place/location	▪ Original equipment manufacturing plant ▪ Mainly commercial vehicle sector
Return of identical product?	Yes

Product recovery operation	***Remanufacturing***
Quality level targeted	▪ 'As good as new' ▪ Meets quality and product specifications of new goods
Process description	▪ Complete disassembly to the lowermost part level ▪ Reprocessing (e.g. machining, abrading, honing) ▪ Inspection and identification ▪ Replacement of worn-out and defective parts ▪ Tests on original equipment ▪ Technological upgrades possible ▪ Equal warranty as there is for new products
Place/location	Remanufacturing plant
Return of identical product?	No

Table 2: Product Recovery Operations in the Automotive Sector
(Source: based on Waters, 1984; extended by research findings)

Within this research, repair is seen as an extension of the product life cycle and means the reconstruction of a part or component to working order. Repair can be less expensive than remanufacturing. However, if there are extensive damages, a remanufactured product might be the inexpensive option. One of the most significant differences between repair and remanufacturing is the fact that after a repair process, the owner of the part receives the exactly identical part that has been handed in for repair. In the case of a radio, for example, the owner can still see traces of wear, such as scratches on the front cover. Within remanufacturing, the customer receives the same type of product (e.g. same product variant), but it is not identical to the returned product. In almost all cases the remanufactured product is composed of parts from many different products, as it is the case with car engines. The process in-between repair and remanufacturing is the factory overhaul, which is often performed in the commercial vehicle sector. Gearboxes or engines, which are overhauled at the original manufacturing plant, will achieve the same performance as new products. However, their durability is less than that of a remanufactured product. A factory overhaul generally requires a longer waiting-time for the customer, since the identical product is returned. Remanufactured engines, on the other hand, are often distributed from stock and therefore available immediately. Target groups for factory overhaul include the second and third owners of a car, who aim at an additional and inexpensive offer to overhaul their aggregates with repairs of minor scope (Company A/B, 2000).

2.4 Closed-Loop Supply Chain Management

As previously noted, it may be argued that logistics management has, over time, developed into supply chain management. In the course of the literature review, it was found that the same was true for closed-loop supply chain management. Reverse logistics seemed to have developed into closed-loop supply chain management in the mid to late 1990s. This strongly resembles the evolution of logistics towards traditional supply chain management in the 1980s. This statement can be underpinned by the relatively large number of contributions published on reverse logistics (e.g. Stock, J, 1992; Fleischmann *et al.*, 1997; Tibben-Lembke, 1998; Rogers and Tibben-Lembke, 1999) and comparatively fewer and later articles in the area of closed-loop supply chain management (e.g. Rowley, 2000; Guide and Van Wassenhove, 2000; Guide and Van

Wassenhove, 2002a, 2003b). Figure 4 represents the similarities between the development of supply chain management and closed-loop supply chain management.

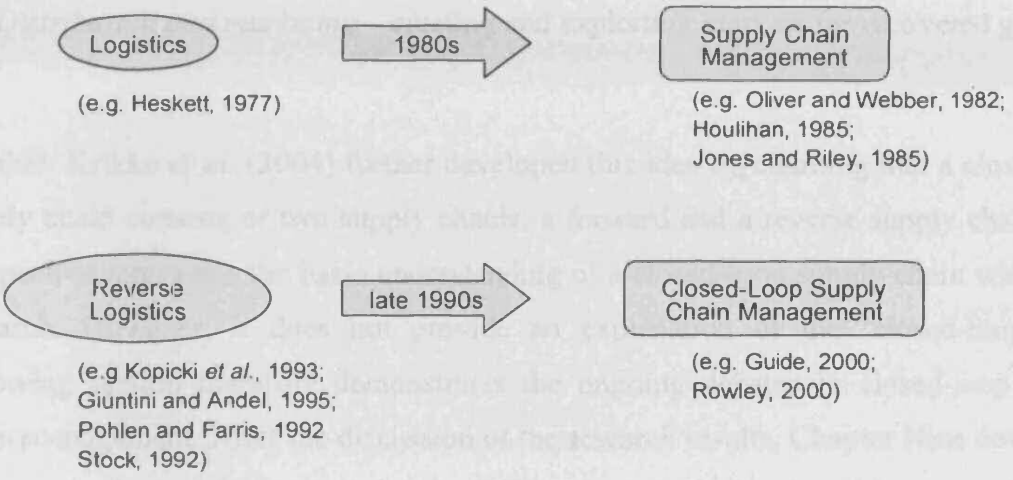


Figure 4: The Evolution of Traditional and Closed-Loop Supply Chain Management

2.4.1 The Closed-Loop Supply Chain

The term closed-loop supply chain has not appeared as such in the literature until the beginning of this century (e.g. Guide and Van Wassenhove, 2000). Several authors have spoken of 'reverse supply chains', a topic which was mainly discussed in practitioner circles (e.g. Cruz, 2000; Kemp, 2001; Morrell, 2001; Serant, 2001). However, a clear definition of closed-loop supply chain only seems to have emerged in the years 2002 and 2003. In their earlier work, Guide and Van Wassenhove (2000) discuss closed-loop supply chains for refillable containers, photocopier remanufacturing and the re-use of consumer electronics. The authors argue that all these closed-loop supply chains have common features, such as product acquisition, reverse logistics, inspection, disposition and reconditioning, amongst others. Guide and Van Wassenhove (2000) also explain that despite these commonalities, not all closed-loop chains are alike. In 2003, a rather general definition of the closed-loop supply chain was developed by Guide and Van Wassenhove (2003b). They define a closed-loop supply chain as a supply chain with traditional forward activities, which has been extended by further activities:

- *Product acquisition* – obtaining the products from the end-users
- *Reverse logistics* – returning the products from the points of use to a processor
- *Test, sort and disposition* – determining the condition of the products
- *Recovery* – activities, such as direct re-use, repair, remanufacture, recycle, disposal
- *Distribution and marketing* – creating and exploiting markets for recovered goods

In 2004, Krikke *et al.* (2004) further developed this idea by claiming that a closed-loop supply chain consists of two supply chains: a forward and a reverse supply chain. This perspective represents the basic understanding of a closed-loop supply chain within this research. However, it does not provide an explanation of the 'closed-loop'. The following section therefore demonstrates the ongoing debates in closed-loop supply chain management. After the discussion of the research results, Chapter Nine develops a new terminological framework for the field and presents the closed-loop supply chain structures for the automotive remanufacturing sector.

2.4.2 Closed-Loop Supply Chain Structures

The literature often refers to the closed-loop supply chain model by Thierry *et al.* in 1995 which they have termed the 'integrated supply chain'. This chain of companies has been defined as a supply chain, which comprises service, product recovery, and waste management activities. Figure 5 shows their supply chain model. In this model, products return from the end-user to undergo a product recovery operation, such as re-use, repair, remanufacture or recycling, for example. Thereafter, products are integrated back into the 'forward' supply chain.

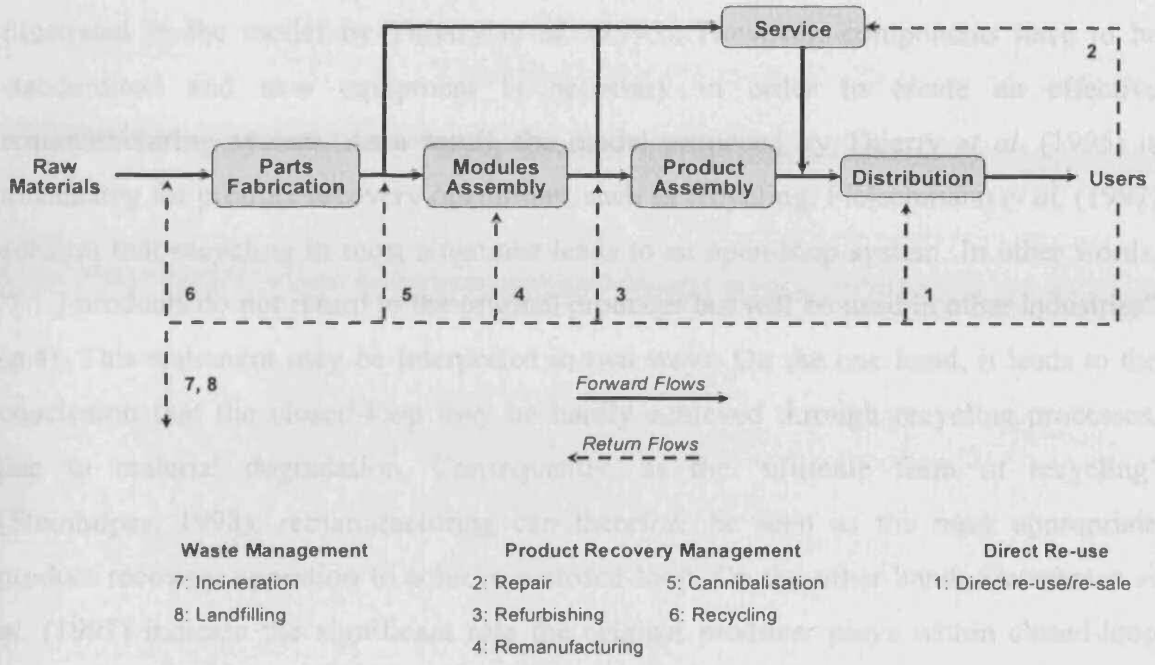


Figure 5: Integrated Supply Chain

(Source: reproduced and slightly adapted from Thierry *et al.*, 1995, p.118)

The case company investigated by Thierry *et al.* (1995), the copying-machine manufacturer CopyMagic, indeed undertakes various resource recovery operations: repair, cannibalisation and recycling. Unlike to what has been shown in the theoretical model (Figure 5), the output of these activities does not flow back into the forward supply chain. Instead, the recovered materials and products leave the loop for a simple reason:

> *Finding markets for recycled materials is notoriously hard. Reusing these materials in manufacturing new products provides a (partial) solution for this problem, providing the quality of the materials is "as good as new" and the customers accept the use of recycled materials.*
>
> (Thierry *et al.*, 1995, p.126)

Although CopyMagic uses its recovery activities to advertise its products, the company still has to convince the customers that the product quality is maintained when recycled materials are used in manufacturing. Remanufacturing of components is seen as the only

recovery option where the recovery output is led back into the forward supply chain as illustrated in the model by Thierry *et al.* (1995). However, components have to be standardised and new equipment is necessary in order to create an effective remanufacturing system. As a result, the model proposed by Thierry *et al.* (1995) is misleading for product recovery operations, such as recycling. Fleischmann *et al.* (1997) confirm that recycling in most situations leads to an open-loop system. In other words, "[...] products do not return to the original producer but will be used in other industries" (p.4). This statement may be interpreted in two ways. On the one hand, it leads to the conclusion that the closed-loop may be hardly achieved through recycling processes, due to material degradation. Consequently, as the 'ultimate form of recycling' (Steinhilper, 1998), remanufacturing can therefore be seen as the most appropriate product recovery operation to achieve a closed-loop. On the other hand, Fleischman *et al.* (1997) indicate the significant role the original producer plays within closed-loop supply chain management. As a result, it may be assumed that the opportunities of integrating reverse flows into forward supply chains are limited and that the original producer plays a central role within the closure of the loop.

Models developed by further contributors in the area (e.g. Guide *et al.*, 1999; Majumder and Groenevelt, 2001b; Meade and Sarkis, 2002; Mahadevan *et al.*, 2003) adhere close to the approach by Thierry *et al.* (1995) and mainly present modifications of Figure 5. These models all assume a general 'forward' supply chain from raw material through parts fabrication, modules assembly, product assembly, distribution to the customer or user. However, the major critique of these models is the assumption that products or parts re-enter this forward supply chain after recovery and at specific points. Even very recent publications within the area of closed-loop supply chain management still assume that the output of a recycling operation enters an alternative (forward) supply chain at the raw material stage (e.g. Krikke *et al.* 2004). Remanufacturing outputs hereby serve as inputs for component manufacturing in original and alternative forward supply chains. These models may be an accurate representation of reverse flows in other industries. However, it must be examined whether these routes occur within the automotive sector.

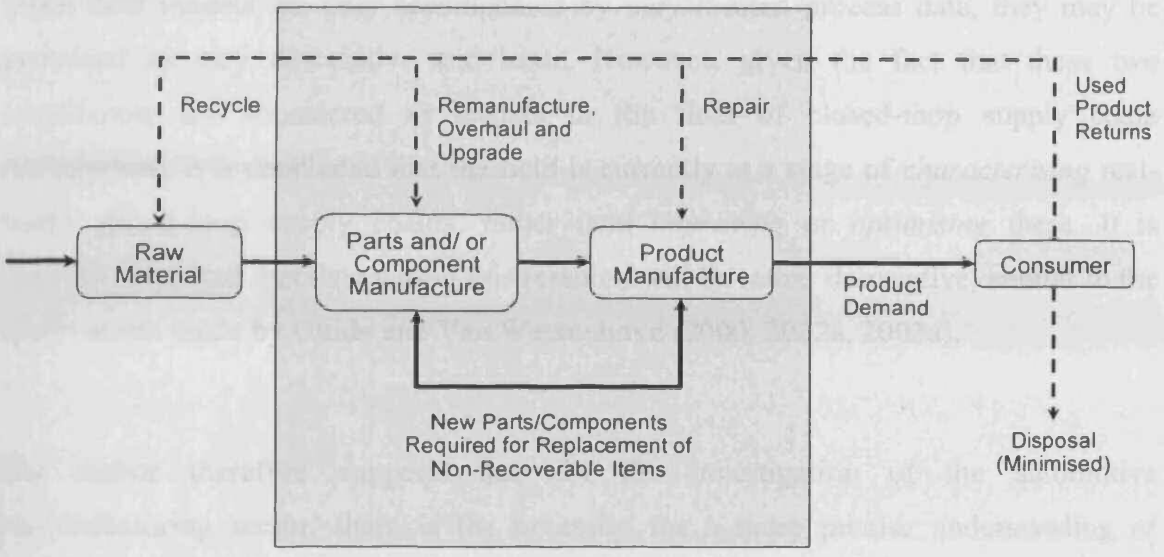


Figure 6: A Recoverable Product Environment
(Source: reproduced and slightly adapted from Guide *et al.*, 1999, p.222)

There are certain difficulties within the application of the above models on the automotive sector. Applying the theoretical models to the automotive industry, it becomes clear that a closed-loop would be achieved, if the remanufactured components are fed back into the forward supply chain and therefore built into new cars. However, current industry practice differs from such a closed-loop system, since remanufactured items are sold in the aftermarket.[4]

Guide and Van Wassenhove (2000) have therefore filled a gap by introducing basic, industry-specific models (supplier, manufacturer, retailers and customers) for toner cartridge re-use, single-use camera re-use as well as more extensive models on photocopier and cellular telephone remanufacturing. None of the suggested models investigates remanufacturing of car engines or automotive electronic devices.

[4] This has been confirmed by Ferrer and Whybark (2001) who argue that "new vehicles are assembled exclusively from new components, generally produced by a few large manufacturers. Replacement items, however, are usually remanufactured" (p.113).

Since their models are only accompanied by very limited process data, they may be perceived as very descriptive and basic. However, given the fact that these two contributors are considered as leaders in the field of closed-loop supply chain management, it is concluded that the field is currently at a stage of *characterising* real-world closed-loop supply chains, rather than *improving* or *optimising* these. It is therefore expected that data within this research will be rather descriptive, similar to the observations made by Guide and Van Wassenhove (2000, 2002a, 2003a).

The author therefore suggests that for the investigation of the automotive remanufacturing sector, there is the necessity for a more precise understanding of 'closed-loop' and 'closed-loop supply chain'. The first aim of this research is therefore to define the closed-loop and develop the closed-loop supply chain for an automotive context. Furthermore, the research seeks to map real-world, industry-specific closed-loop supply chains for the automotive sector, with a particular focus on remanufacturing. The first Research Question (RQ) is therefore phrased as follows:

Which existing closed-loop supply chain structures are relevant to the automotive industry? (Research Question 1)

This research question will be split into two parts. The first model will demonstrate the closed-loop supply chain for remanufactured automotive engines, whereas the second model will focus on remanufactured electronic devices. The results with regard to this question are presented in Chapters Six (engines) and Seven (electronics) and summarised by an in-depth discussion in Chapter Nine.

2.4.3 Reverse Logistics

This dissertation does not focus on reverse logistics as a stand-alone activity, but rather perceives it as an integrated part of the closed-loop supply chain, as previously discussed. Earlier sections in this chapter have assumed and demonstrated that reverse logistics has developed into closed-loop supply chain management. As a result, there is the need to discuss previous contributions in the area of reverse logistics. Moreover, due to the much earlier contributions in the field of reverse logistics and the thematic basis this area provides for closed-loop supply chain management, this section aims to review literature on reverse logistics.

Many of these contributions have investigated reverse logistics in isolation, though main contributors in the area of closed-loop supply chain management, such as Guide and Van Wassenhove (2002b), identify reverse logistics as one of the closed-loop supply chain's key components. Although there is a large body of literature on reverse logistics, the discipline is still perceived as underdeveloped (Fleischmann, 2003). Giuntini (1996) confirms that "Reverse Logistics Management is currently in the introduction stage of its life cycle. It will take 10-15 years before it becomes truly institutionalized within the supply chain" (p.86).

There are diverse definitions of reverse logistics in the literature. According to Rogers and Tibben-Lembke (1999) and Bayles (2001), in reverse logistics, the flow of raw materials, in-process inventory, finished goods and information does not circulate from the point of origin to the point of consumption, but the opposite way. "More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal" (Bayles, 2001, p.258). However, there are further ideas. Kellog (1994), for example, includes the reduction of materials in the forward flow, hence, fewer materials flow back. This goal then can be achieved through re-use and recycling.

De Brito *et al.* (2003a) have pointed out that there are various reasons for product returns. They distinguish between manufacturing, distribution and customer returns. For this research, however, a different typology needs to be developed. In the case of commercial returns, such as wrongly delivered or damaged goods, as well as overstock, 'slow sellers' or seasonal inventory, no product recovery as such is required, since some

products are merely re-labelled or re-packaged. Although a reverse logistics activity is involved, such product returns are not considered as a part of this research. However, it must be noted that in the United States, return flows play a significant role within a retail context, since return policies tend to be more extensive and flexible than in Europe. As a result, American contribution in the area of reveres logistics are largely influenced by commercial returns (e.g. Stock, 1992; Rogers and Tibben-Lembke, 1999). In Europe, end-of-life and end-of-use products seem to dominate the discussion (see De Brito and Dekker, 2003a; De Brito *et al.* 2003a).

Following the above discussion, the definition of reverse logistics for this thesis is taken from Ferrer and Whybark (2000). Reverse logistics is hereby defined as "retrieving used products and components from customers and returning them to a processing facility [...]" (p.56).

2.5 Remanufacturing

Remanufacturing has been identified as a high-value product recovery operation, which is able to recover the value-added of a product through an extensive recovery process. Moreover, products after recovery achieve an 'as good as new' standard. This section firstly discusses the history of remanufacturing, as well as the players in the remanufacturing market. Thereafter, remanufacturing process structures are discussed.

2.5.1 The History of Remanufacturing

Table 2 in Section 2.3.2 has defined automotive remanufacturing as the transformation of an end-of-life product into a product with a condition that meets the specifications of a new product. Material recycling only occurs when parts and components cannot be reworked. One specific characteristic of remanufacturing is the fact that parts and components retain their original identity. Remanufacturing further differs from recycling or repairing since it also recovers the value that was originally added to the raw material (e.g. cost of labour, energy). Therefore, this type of recovery makes a higher economic contribution per unit of product compared to recycling (The Remanufacturing Institute, 2003). Used products, which serve as 'raw material' to the remanufacturing process are defined as 'cores' (Ferrer and Whybark, 2000). However, some contributors (e.g. Kerr and Ryan, 2001) refer to the disassembly of the product into 'cores'. This perspective is accurate if it is applied to a product with subassemblies attached. However, the author will refer to the definition of 'core' by Ferrer and Whybark (2000), since their explanation reflects the perspective of the remanufacturing sector.

The automotive sector has been among the first industries to practice remanufacturing. However, the historic rationale behind remanufacturing is manifold and does not originate from one particular source. Compared to the manufacturing and distribution of new vehicles, automotive remanufacturing has remained largely invisible (Waters, 1984). Only recently is remanufacturing gaining scientific significance in a variety of industry sectors, such as photocopier remanufacturing (Kerr and Ryan, 2001), the

remanufacturing of cellular telephones (Guide and Van Wassenhove, 2003a) or single-use camera remanufacturing (Guide and Van Wassenhove, 2002b).

Automotive remanufacturing emerged in terms of economic significance during the depression and further accelerated in the Second World War (Seitz and Wells, 2003). In the United States, the American Department of Defence is still the largest remanufacturer (Environmental Protection Agency, 1997) and automotive remanufacturing accounts for the largest civilian remanufacturing activity (Nagler, 1999). However, there are further elements which have contributed to the remanufacturing sector's success. Ferrer and Whybark (2001) explain that many vehicle component remanufacturers are located in the Southeast of the United States, which is ascribed to the roots of auto racing in this region. According to Ferrer and Whybark (2001), these remanufacturing firms initially supported the racing industry with completely remanufactured engines or components. These small workshops have furthermore naturally progressed from a racing car focus to the inclusion of passenger car component remanufacturing. Waters (1984) claims that the first independent remanufacturing business in the United States was established in 1929 by watchmaker Albert S. Holzwasser, whose business had initially focused on the repair of clocks and speedometers for automobile dealers. When visiting his customers, Holzwasser observed that dealers discarded all parts and components which could not be repaired. Hence, what was probably the first American remanufacturer was created on the basis of a perceived business opportunity.

European remanufacturing began with the company *Frimatec* in 1931, which claims to be the first German automotive remanufacturer and VEGE-Motoren B.V. (2002) in the Netherlands, which was established in 1936. In 1947, Volkswagen, as the first German vehicle manufacturer, began to remanufacture in a large-scale operation.

Despite this long history of remanufacturing within the automotive sector, academic research has only begun to investigate the industry in 1976, with Lund being its principal theoretician (Waters, 1984). Steinhilper (1998) further claims that, although remanufacturing existed since the beginning of the industrial age, there is little known about remanufacturing amongst consumers and academics.

> *It seems, however, that just recently there has been an awakening no longer to leave aside the chances of remanufacturing as a brilliant idea for a proactive integration of technology and the environment, serving both new markets as well as a responsibility for the nature and the future of our society.*
>
> (Steinhilper, 1998, p.11)

Steinhilper (1998) therefore discusses remanufacturing in his book, covering the basics of remanufacturing, such as the differences to other recovery operations and the illustration of the main operational processes. He does not particularly focus on one industry sector. Nevertheless, the tradition of automotive remanufacturing (engines, starters, alternators, and clutches) influences the discussion. Steinhilper's work targets the practitioner audience and he does not apply findings to a supply chain context. Although this dissertation's findings will show similarities to the findings by Steinhilper (1998), particularly regarding the actual remanufacturing operation, this thesis takes a rather academic approach by applying the research findings to a supply chain context.

Other contributors in the field, for example Ayres *et al.* (1997), have focused on a variety of industry sectors, such as the remanufacturing of photocopying machines. They have come to the conclusion that handling the return flow of cores is significantly easier for a company which takes care of its own products, rather than operating through wholesalers. This aspect has particular significance regarding remanufacturing in the automotive sector, as vehicle manufacturers operate through an intense network of franchised dealers, subsidiaries, and wholesalers. Ayres, R *et al.* (1997) furthermore note that it is comparatively more difficult to trace back and initiate the take-back of a long-lived product, compared to the same processes for a short-lived product. According to Waters (1984), the ideal product for remanufacturing is a durable good which comprises a high percentage of recoverable material and where the scrap value is significantly lower than the economic value of the product. Remanufacturing has also become a way of recovering products, which cannot be recycled or where recycling is economically not competitive. A good case in point is the remanufacturing of car tyres, called 'retreading' (Ferrer, 1997b). In this case, the recycling of the tyres' materials (pyrolysis) is not viable in economic terms.

2.5.2 Players in the Automotive Remanufacturing Sector

Chapter Five, which aims to portray the automotive industry and the relationship between individual players, will elaborate on the European remanufacturing sector with regard to its size, structure and the product range. At this point, however, the author felt it was necessary to give an overview of players within the automotive remanufacturing sector, since subsequent chapters are based on the understanding presented in this section. Hence, this section clarifies the terminology with regard to the types of players that can be found in the automotive remanufacturing sector.

OEM Remanufacturers

According to Lund (1984b), OEM remanufacturers are original equipment manufacturers, whose focus is on the production of new parts and remanufacturing is an added business. Applied to this research in the automotive sector, OEM remanufacturers may therefore be either vehicle manufacturers or their (first tier) suppliers. Both may be manufacturers of the original equipment. With regard to the size of the businesses, OEM remanufacturers tend to be larger in terms of sales and employment (Sherwood and Shu, 2000; Schwarck, 2003a).

Sherwood and Shu (2000) have observed that OEM engine remanufacturing working practices differ from remanufacturing procedures undertaken by independents. According to Sherwood and Shu (2000), independents' priority is the saving of a particular part, whereas OEMs tend to scrap parts that are uneconomical to repair or would take longer than average to remanufacture. In fact, independent engine remanufacturers have developed special repair methods in order to utilise as many parts from a core as possible. This observation has been confirmed by Szuhy, who claims that, within the independent sector, "[...] only with great reluctance are pieces ever thrown out" (in Waters, 1984, no page given).

With regard to the re-assembly activities in remanufacturing, products are generally produced in small batches. OEMs also have small batch sizes, but still larger batches than the independents. Szuhy (in Waters, 1984), who has expertise with OEM and independent remanufacturing explains that in an independent remanufacturing

environment, a thirty minute batch is considered a 'long run'. In addition, independents seem to depend on the original equipment manufacturer with regard to design information.

> *...the original equipment manufacturer has an advantage over the independent firm. The remanufacturing process is fairly easy for the OEM because it is responsible for the original vehicle design and its assembly. Access to data, such as dimensions, material, performance, and other specifications, removes the need to research the information. Many OEMs refuse to share this information with independents forcing them to do the research. Often costly and inefficient, some information may not even be obtained in this way.*
>
> (Schwartz, 1995)

Guide (2000) claims that in the United States, original equipment manufacturers remain largely disengaged and account for only 5% of the total industry. In the European automotive sector, however, car manufacturers possess a larger market share than US remanufacturers (Schwartz, 1995). This relatively higher share of OEM remanufacturers in Europe may be a result of the increase in European take-back laws, in which OEMs are responsible for product take-back, recovery and the coverage of all costs (Fleischmann *et al.*, 2000). "In the USA, OEMs are often not formally responsible and product recovery is driven by private, commercial initiatives" (Fleischmann *et al.*, 2000, p.661).

Within the German remanufacturing sector, vehicle manufacturers have established remanufacturing plants for their own remanufacturing purposes, such as DaimlerChrysler/Mercedes-Benz in Berlin and Volkswagen in Kassel. BMW in Landshut additionally remanufactures Land Rover engines for the Ford Group (BMW Group, 2003).

Independent Remanufacturers

Lund (1984b) defines independent remanufacturers as those businesses, which solely focus on the remanufacturing of products produced by others. According to Schwartz (1995) these remanufacturers do not have any connection to the vehicle or the original manufacturer. Lund (1984b) claims that the typical independent remanufacturer is a private, small corporation, "[...] usually operating on a hand to mouth basis competing in a complex and uncertain environment" (Ferrer and Whybark, 2001, p.113).

Independent remanufacturers not only need to acquire design information from the OEMs, but also depend on new parts to be included in the remanufacturing operation. In some cases, these parts are only available from the original manufacturer or the supplier. This is particularly true for parts in over- or undersizes, such as bearing shells. This dependency can be critical with regard to delivery times or prices. Hence, some independent players manufacture their own new parts. They frequently incorporate modifications of the original design or upgrade existing technology (Waters, 1984). Moreover, a whole business sector has developed around remanufacturers, providing them with new parts such as cylinder liners, new pistons or bearing shells, since vehicle manufacturers have tried to exclude their independent competitors from access to (new) replacement parts (Waters, 1984). In the United States, these practices by OEMs have been declared as 'unfair trade practices' and have ceased (Waters, 1984). However, as this research will show, new parts procurement has proven to be a challenge for OEM remanufacturers, too, who often compete for parts with the 'new assembly line'.

Compared to OEM remanufacturers who tend to remanufacture products from their own brands, independent remanufacturers select whose parts they buy and remanufacture (Sherwood and Shu, 2000). Independent players therefore often provide a whole range of remanufactured brands. One of the largest independent players in the world, VEGE-Motoren in The Netherlands, for example, offers remanufactured engines, engine parts and gear boxes from 16 different brands (VEGE-Motoren B.V., 2002). According to Sherwood and Shu (2000), the throughput at independent outlets is only a few engines a day. This statement is true for the largest share of independent remanufacturers, but not for the biggest independent players, who may achieve sales and employment figures

comparable to major OEM remanufacturers. In many cases, independent players do not just undertake remanufacturing activities, but have extended their product range to related business activities, such as the production of new parts which are used within remanufacturing.

Subcontracted Remanufacturers

Within this research, a subcontracted remanufacturer is defined as a business contractually bound to an original equipment manufacturer. This may be a business which solely provides services to a vehicle manufacturer or an original equipment parts manufacturer. Generally, subcontracted remanufacturers provide services for an OEM, while remanufacturing for their own purposes as independent players. A major advantage of subcontracted remanufacturers is the access to specification sheets and design information which is provided by the OEM, so that quality levels and product specifications can be met. "In some cases, the independent remanufacturer may be operating under a franchise from a major OEM such as Ford or GM's Detroit Diesel/Allison Division, in which case technical assistance and parts are available from the OEM" (Lund, 1984b, p.12). However, not just technical specification sheets but also equipment and machinery is provided by the OEM. Mostly, this machinery comprises outdated equipment of the production line on which the products were originally produced. In addition, the OEM may take care of the core collection, too. The Wealdstone Engineering Ltd. in the UK, for example, remanufactures engines for Ford and at the same time, offers a variety of other, remanufactured products. Autocraft Industries UK remanufactures Jaguar engines for Ford and also undertakes the repair of new parts for the OEM. If a cylinder head fails the quality test on the assembly line for new engines, the part is sent to Autocraft Industries for rework, such as machining, for example. Moreover, a subcontracted remanufacturer may provide further services, such as the machining of engine parts, low volume assembly, warranty investigation or dynamometer testing (Autocraft Industries UK, 2003).

A third form of the subcontracted remanufacturer is the OEM remanufacturer who provides services to other players in the market. BMW, for example, remanufactures

engines for Ford (Land Rover). Further subcontracted OEM remanufacturers include first tier parts manufacturers, such as the German company Luk, who is a direct supplier of clutches but also remanufactures parts for the OEM.

Furthermore, subcontracted remanufacturers may find themselves within a conflict of aims, since OEM products may compete with their own aftermarket range of new (non-OE) or remanufactured products.

2.5.3 Generic Remanufacturing Models

In this section, the actual recovery process is observed in more detail. Process structures for remanufacturing will be discussed. They differ from closed-loop supply chain structures by the characteristic that the remanufacturing models display in-plant processes. In other words, remanufacturing models display the operations within the recovery facility, which usually represent one echelon in a typical closed-loop supply chain.

Generic recovery models of remanufacturing processes have been discussed by Guide (2000), for example. However, there are also more specific remanufacturing models, for example by Kerr and Ryan (2001) for photocopier remanufacturing, refrigerator recovery (Krikke *et al.*, 2003) or personal computer remanufacturing (Ferrer, 1997a). However, few models exist for automotive parts and component remanufacturing. Van der Laan (1997) has discussed automotive remanufacturing from a theoretical perspective. He does not present a process structure of the remanufacturing operation. Steinhilper (1998) looks at remanufacturing and repair from a process perspective and Langella (2003) discusses automotive engine remanufacturing, but does not put a particular emphasis on the description of in-plant processes. More generally, contributors tend to focus on mapping the closed-loop supply chain, thereby labelling the remanufacturing plant as 'reprocessing' (e.g. Krikke *et al.*, 2003)), 'remanufacturer' (e.g. Guide and Van Wassenhove, 2003a) or 'component recovery' (e.g. Spengler and Schröter, 2003), without discussing the processes in detail. In some cases, the understanding of closed-loop supply chain and in-plant processes become indistinct (see Krikke *et al.*, 2001, p.3697, for example). The generic model for automotive remanufacturing presented by Ferrer and Whybark (2001), as shown in Figure 7,

represents the material flow process, despite omitting important process steps, such as cleaning, inspection and sorting as well as the actual parts recovery. This section therefore discusses the complete remanufacturing process.

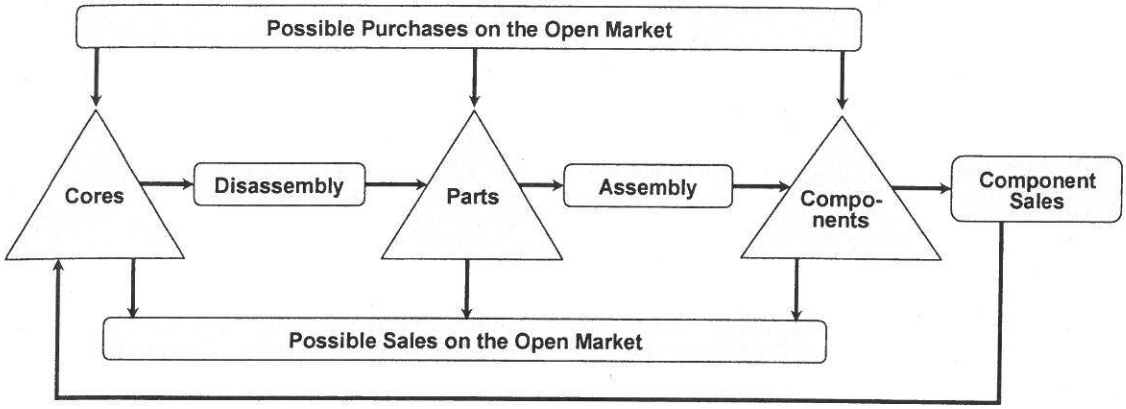


Figure 7: Material Process Flow Diagram for Automotive Component Remanufacturing (Source: reproduced from Ferrer and Whybark, 2001, p.114)

As previously noted, the used products (cores) serve as raw material to the remanufacturing process. The first process step in a remanufacturing plant is therefore the disassembly process, in which the products are completely dismantled. Within automotive remanufacturing, this includes process steps, such as loosening screws, or joinings without damaging the product. One important decision within the planning of a remanufacturing operation is the planning of the disassembly schedule, which specifies the type and quantity of cores to be disassembled (Ferrer and Whybark, 2001). Hereby, disassembly planning has to consider anticipated scrap rates, already disassembled cores, as well as already disassembled and recovered parts. Johannes (1995) further adds that, on the basis of past disassembly rates, the amount of cores to be disassembled is increased by an additional number of cores, in order to exclude the uncertainty within the core quality. This process has been termed 'over-stripping' in the industry. Moreover, disassembly planning is complicated by making use of alternative parts to replace unavailable parts, as pointed out by Johannes (1995) and Langella (2003).

Other parts may only be used in re-assembly with the corresponding 'wear parts', a problem which has been identified as 'mating part lost' by Sherwood and Shu (2000). If

one part of a group is lost, the remaining parts cannot be used. This may be the case if one connecting-rod is lost. Disassembly is still undertaken manually, since experiments have shown that robots are not capable or economically viable in dealing with disassembly (Steinhilper, 1998).

As opposed to the above model by Ferrer and Whybark (2001) in Figure 7, Steinhilper (1998) includes a further process step in remanufacturing: the cleaning process. The cleaning process includes de-greasing, de-oiling or de-rusting and may be undertaken by 'heat treatment' or 'chemical baths' (e.g. VEGE-Motoren B.V., 2002).[5]

Within large remanufacturing operations, parts are cleaned in groups of similar products. Hence, they are detached from the original product they have formed. In small reconditioning workshops, parts of one specific product may be kept together, since smaller outlets may work on a remanufacture-to-order basis. Inspection and sorting follows the cleaning process. Parts are classified into three groups, depending on the recovery level required. Sherwood and Shu (2000) give a complete discussion on failure and scrap modes within automotive remanufacturing. Further parts may be recoverable, other parts can be re-used directly without recovery (Johannes, 1995).

Thereafter, the actual product recovery process takes place. This may vary, depending on the product. There is, for example, a significant difference between mechanical and electronic remanufacturing, which will be discussed in Chapter Five in more detail. Within automotive remanufacturing, the actual parts recovery comprises processes, such as grinding, boring, turning and milling (Steinhilper, 1998).

The remanufacturing operation is completed by the re-assembly and testing of the product. According to Steinhilper (1998), re-assembly takes place at small batch assembly lines. After re-assembly, products undergo quality tests on test benches (e.g. VEGE-Motoren B.V., 2002). Guide (2000) furthermore adds that the majority of remanufacturing firms that have participated in his survey use a combination of make-to-stock, make-to-order and assemble-to-order strategies.

[5] For a detailed discussion on cleaning technology, please refer to Steinhilper (1998), pp. 46-49.

Although Steinhilper (1998) presents an extensive descriptive account of automotive remanufacturing operations, there is the need for the establishment of an in-plant remanufacturing process structure with detailed process data, such as throughput times or scrap rates. Furthermore, complicating characteristics within automotive remanufacturing need to be unravelled. Research Question 2 will therefore be phrased as:

Which existing remanufacturing process structures are relevant to the automotive industry? (Research Question 2)

2.5.4 Uncertainty within Remanufacturing Operations – Reverse Logistics

Guide and Van Wassenhove (2002b) explain that recovery activities are much less predictable than traditional manufacturing processes, due to the larger degree of uncertainty involved. This begins with the differences between forward and reverse logistics. In the 'forward' supply chain, goods are delivered from one to many distribution points, whereas in closed-loop supply chain management, products return from many sources (end-users) to one destination (processor). This phenomenon is called 'many to one transportation' (Tibben-Lembke and Rogers, 2002) or 'many to one distribution points' (Rogers *et al.*, no date given). In addition, within a product recovery environment, not just customer demand, but also the availability of cores (return flow) has to be forecast. However, there is a large uncertainty of backward-flows in terms of quality (condition), quantity and timing. Fleischmann *et al.* (2001) speak of a "[...] mismatch between supply and demand with respect to timing and quantity in a recovery network" (p.158). Furthermore, the product mix of cores can vary substantially in terms of condition or type, with the volume for some of the products being very low (Ferrer and Whybark, 2000). Tibben-Lembke and Rogers (2002) claim that reverse logistics flows follow the trends of forward logistics processes, but with a time-lag.

Table 3 gives an overview, of what main contributors in the area have identified as the major obstacles within product recovery management. The table therefore provides a basis for the discussion of the main issues which the literature suggests. Some of the

issues presented in Table 3 are entirely related to the product return flows (e.g. integration of forward and reverse flows; uncertainty of reverse flows), others are related to in-plant remanufacturing processes. With a specific focus on remanufacturing, Guide (2000), for example, has determined seven characteristics which complicate production planning and control activities in a remanufacturing environment. They are the following (adapted from Guide, 2000):

- Uncertainty in timing and quantity of returns
- Uncertainty in quality of returns
- Balancing returns with demand
- Product disassembly
- Requirement of a return collection system
- Return of identical product (if applicable)
- Stochastic routings for materials within remanufacturing processes and highly variable process times

Author(s)	Collection Structure Complexity	Uncertainty of Return Flows: Quantity, Quality, Timing	Integration of Forward and Reverse Flows	Complex Inventory Management	Production Planning and Control	Finding Markets for Recovered Products	Achieving Economies of Scale
Beamon (1999)	✔	✔	✔	✔	✔		
Beullens *et al.* (2003)	✔						
De Brito and Koster (2003)				✔			
Ferrer and Whybark (2000)	✔			✔	✔		✔
Fleischmann *et al.* (1997)		✔	✔	✔			
Fleischmann *et al.* (2000)				✔	✔		
Goggin and Browne (2000)	✔	✔					
Guide (2000)	✔	✔			✔		
Guide and Van Wassenhove (2002)	✔	✔			✔	✔	
Guide *et al.* (2000)	✔	✔	✔				
Kiesmüller *et al.* (2003)			✔	✔			
Krikke (2001)		✔	✔		✔		
Minner (2001)			✔	✔		✔	
Nagel and Meyer (1999)	✔						
Pohlen and Farris (1992)	✔					✔	✔
Rogers and Tibben-Lembke (1999)		✔					
Stock *et al.* (2002)	✔					✔	
Thierry *et al.* (1995)			✔			✔	
Toktay *et al.* (2003)		✔					
Veerakamolmal and Gupta (2000)	✔		✔	✔	✔		

Table 3: Process Uncertainties within Product Recovery Management

2.5.5 Complicating Factors in Remanufacturing and Quantitative Approaches

This section outlines aspects that complicate remanufacturing. A particular emphasis is hereby put on the review of literature which takes a quantitative perspective or research that has applied quantitative approaches. The review of this specific literature seeks to identify research needs this dissertation may satisfy by taking a qualitative approach. According to Guide (2000), most research associated with remanufacturing is quantitative and typically consists of mathematical representations of production planning strategies. Moreover, Guide claims that a variety of problems were addressed by previous research, though significant areas have been neglected, such as empirical case study research. However, "[...] the majority of these studies are limited to a specific functional activity, such as scheduling" (Guide, 2000, p.468). Ferrer and Guide (2002) further add that previous research on remanufacturing has been limited on narrow aspects, including network design, shop floor control or inventory management.

This section, however, does not review work on quantitative approaches outside remanufacturing plants, such as the design of product take-back structures. Instead, this section takes a narrow perspective by reviewing previous quantitative research on issues which are relevant to this dissertation, focusing on remanufacturing. As Guide (2000) has noted, much of the previous research has emphasised one specific issue within or related to remanufacturing operations. This point is supported by Krikke *et al.* (2001), who have identified that many models within previous research investigate elements of remanufacturing separately. Therefore, this section gives an overview of previous work by key contributors in the area and identifies the specific topics that were addressed. As a guideline, the typical remanufacturing process steps (e.g. core delivery and storage, disassembly and parts recovery) are used as categories for classification.

Uncertainty within Core Acquisition and Core Return

The return of used products is the first activity which concerns the remanufacturing echelon in the closed-loop supply chain and may be described as the process step 'core delivery'. Various researchers have demonstrated the uncertainty incorporated in

product acquisition. According to Ferrer and Whybark (2001), the quantity of products being returned, the so-called core supply, hardly ever achieves 100% of the units sold, therefore incorporating the uncertainty of return. Moreover, it can be assumed that the longer the time-span between product sale and product return, the fewer cores return. In order to determine the return times of cores, various contributors have established quantitative models to forecast product returns (e.g. Ferrer and Whybark, 2001; Toktay *et al.*, 2003b). Guide and Van Wassenhove (2001) claim that there is research on return forecasting for re-usable packaging (containers) (e.g. Goh and Verasprasad, 1986; Kelle and Silver, 1989) or commercial returns (e.g. Hess and Mayhew, 1997). However, these are difficult to apply to a remanufacturing environment. In addition, Guide (2000) comments that research on the uncertainty of the timing and the quantity of returns has often taken a narrow perspective on inventory models, which assume that returns are exogenous variables. As a result, there is an academic debate on the question whether return rates are exogenous and whether product returns can be influenced with regard to quality or core price. With regard to this debate, Fleischmann *et al.* (2002) and Guide and Van Wassenhove (2001) are supporting the 'proactive approach' and believe that product returns may be actively influenced by corporate control policies, such as financial incentives.

The opposite view is taken by Hammond *et al.* (1998), who claim that their survey shows that parts availability is the most critical issue in determining remanufacturability. In their eyes, remanufacturers have no choice but to acquire cores for any price. The prices of cores are driven by market forces. However, in the automotive sector, vehicle manufacturers try to outbid independents by paying the customer a rebate above market price, in order to ensure a steady return flow (Hammond *et al.*, 1998). Ferrer and Whybark (2001) further add that uncertainty of core return is largely determined by the lead-time of return.

> *Cores come in at an uncertain rate for several weeks after the corresponding remanufactured component is sold. In addition, some of the expected replacements never do arrive, adding to the uncertainty. Another form of uncertainty in core receipts relates to the core types. It is impractical to require that the trade-in cores correspond exactly to the component types sold. Moreover, it is unlikely that they will exactly correspond to the ones that the manager needs to disassemble for the next assembly schedule.*
>
> (Ferrer and Whybark, 2001, p.114)

From an academic perspective, Guide and Van Wassenhove (2001) argue that return rates may be consciously influenced by remanufacturing companies. Hence, they identify research needs with regard to the development of tools and techniques in order to manage quantity and timing of product returns. Potential research approaches include the assessment of methods, such as leasing and deposits, or the development of forecasting models, in order to predict return rates and volumes (Guide and Van Wassenhove, 2001). Attempts to address this problem have therefore been made by Toktay *et al.* (2003a), for example, who assume that returns are a function of past sales. Moreover, Klausner and Hendrickson (2000) and Kumar and Guide (2002) have developed models on take-back prices for used products, in order to influence quality, quantity and timing of returns. However, these models often make simplified assumptions and may neglect real-world impacts, such as competition in the market as outlined by Hammond *et al.* (1998), in which the calculated price may be suboptimal. An exception is the work by Majumder and Groenevelt (2001b), who have modelled competition between OEM and other remanufacturers for used products. However, they have also confirmed that "the engineering and operations literatures do not consider competition at all" (Majumder and Groenevelt, 2001b, p.9).

Another obstacle within the management of a remanufacturing operation is the time lag between the introduction of a product to the market and its return as a remanufactured product on the aftermarket. Technological developments may complicate the distribution of a remanufactured product, particularly if the introduction to the original market and the distribution of the remanufactured product on the aftermarket lie decades apart, as in the case of car engines. Passenger car engines have undergone significant developments with regard to exhaust specifications. A similar development can be observed in the tyre retreading industry. Today, tyre manufacturers produce tyres with

smaller aspect ratios (measurement which defines the tyre geometry and shape) than the tyres that were previously produced. Within the tyre replacement market, the market share of remanufactured tyres in the aftermarket is decreasing, which is due to 'fit problems' as, for example, aspect ratios (Ferrer, 1997b). Taking a second example, within personal computer remanufacturing, just 5% of all computers that return for remanufacturing can be recovered, since most of the computers are outdated and recovery is not feasible in economic terms (Ferrer, 1997a). Toktay *et al.* (2003a) therefore recommend a statistical investigation to influence return delays and, as a result, reducing core obsolescence.

Disassembly, Recovery Planning and Control

Much of the literature on product disassembly, the planning and the control of remanufacturing operations discusses the uncertainty of the condition (quality) of returns (see Tables 4 and 5). Remanufacturing companies depend on used products as raw material for the process. The incorporation of recovered parts into the final product is one of the key aspects that make remanufacturing competitive in a market which contains new parts (aftermarket). Johannes (1995) claims that within engine remanufacturing, 37% of the overall costs can be allocated to material. On the other hand, the engine manufacturing process for brand-new engines allocates 49% of all costs on material. As a result, the cost-competitiveness of an engine remanufacturing process increases with the increase of remanufactured parts in the process. Section 2.5.2 on players within the remanufacturing industry has demonstrated that in the remanufacturing sector itself, this is a key distinction between independent players, who try to recover as many parts as possible, and OEM remanufacturers, who spend less effort on saving a used part by replacing it with a new part.

According to Guide (2000), the uncertainty of core quality has significant impacts on production planning and control.

> *Remanufacturing firms must obtain products that have failed functionally. Acquiring cores – failed products – requires reverse logistics activities, and these activities, in turn, require significant modifications to traditional production planning and control systems.*
>
> (Guide, 2000, p.471)

The quality of failed products, however, may differ to a large extent at the time of return. Additional waste may occur within the disassembly process of a product. Guide (2000) argues that products, which are not designed for disassembly, are rather unpredictable with regard to material recovery rates. Therefore, the actual rate of returned and usable parts within the returns has to be calculated for product recovery management. Quantitative research has been undertaken by Penev and De Ron (1996) and Lambert (1997), for example, who model the expected residual value incorporated in products returned for recovery. However, according to Guide (2000), there is still a lack of models, which can predict the quantity of materials recovered by the age of the product or the usage rate.

In practice, there are several methods for complementing parts shortages caused by low core return or high scrap rates. Johannes (1995) claims that remanufacturers therefore seek other options for raw material supply, rather than relying on the existing take-back network. Further options include the purchase end-of-life goods from external companies (e.g. independent garages; vehicle dismantlers; core brokers) or increasing the use of new parts and components in the remanufacturing process. However, as previously noted, the larger the amount of new parts in the remanufactured products, the less competitive this product is in the aftermarket. Johannes (1995) further explains that remanufacturers make use of alternative parts to replace unavailable parts. In most cases, these alternative parts are taken from other used products with a different constructional level and are then transformed so that they can replace the unavailable part. Langella (2003) also points out the 'commonality' between cores, whereby the same part or component is found in several product variants or models. Within engine remanufacturing, for example, companies may procure missing parts from other engines. Langella (2003) has approached these issues by modelling disassembly-planning for an engine remanufacturing company. However, he admits that future research must focus on industrial examples, in order to increase the applicability of these models. A further overview of existing research on core disassembly or recovery planning and control is given in Tables 4 and 5.

Inventory Control in a Remanufacturing Environment

There is a large body of literature on inventory management and control for product returns. However, as discussed before, Guide (2000) has criticised that most of the existing research takes a narrow perspective by only focusing on inventory models which assume that returns are exogenous variables. Van der Laan *et al.* (2003) confirm that most available inventory models assume that product returns are independent from demand, in order to ensure the tractability of the models. This section therefore discusses the sources of aspects, which may result in inventory management difficulties. This dissertation may therefore provide insights, which are often neglected by quantitative approaches to problem-solving.

One of the major challenges within inventory management for product returns is the potential increase in inventory through product returns. According to De Brito and Dekker (2003b), this aspect makes inventory control in a product return or recovery environment more difficult than 'conventional' or 'traditional' inventory control.

Product variability and product variety are a second issue, which have an 'unusual' impact on inventory management. Guide and Van Wassenhove (2001) refer to product variability in the quality of products which return for remanufacturing. "This variability makes the tasks of materials planning, capacity planning, scheduling, and inventory management complex and difficult to manage" (Guide and Van Wassenhove, 2001 pp.144-145). Moreover, there is product variety (variants and models) and parts variety, which lead to a rather complex inventory management. Remanufacturers generally receive product returns from several generations and from different technological levels. As opposed to that, in a conventional manufacturing plant there is just one constructional level of the product at a time (Johannes, 1995). Hence, the variety of products (cores) in stock is comparatively larger than in a conventional manufacturing environment. In addition, a remanufacturer stores different types of parts for each product generation, including new, remanufactured and used parts. Consequently, the same part may be available as remanufactured, new or used (and not yet remanufactured). Johannes (1995) explains that there are two causes for a relatively more complex inventory management within remanufacturing. On the one hand, product

returns are classified as 'raw material' within the company. On the other hand, there is the uncertainty of core delivery (day of delivery).

Since inventory management for remanufacturing has been identified as a major challenge, a comprehensive body of operations management literature has developed for this topic. However, there are various points of criticism for current models. The criticism by Guide (2000) with regard to the narrowness of previous inventory models has been outlined above. Moreover, De Brito and Dekker (2003b) argue that contributors in the area of inventory control generally take simplified assumptions in inventory control management for product returns. These simplified assumptions include that the demand and the return flow are characterised as homogeneous Poisson Process. Moreover, it is assumed that return and demand processes are independent from each other (De Brito and Dekker, 2003b). In their work, De Brito and Dekker (2003b) therefore examine the empirical validity of these assumptions. They conclude by arguing that there is the need to adapt these assumptions to create models suitable for non-stationary (real) situations, such as the seasonality of certain products. Further concerns of a limited practical applicability have been raised by Debo *et al.* (2001), who argue that the current quantitative literature assumes that prices, demand rates and the level of remanufacture are exogenous. In addition, it is assumed that consumers do not distinguish between new and remanufactured products.

> *We consider one product. The customer does not distinguish between remanufactured or original items sold by OEM, but distinguishes between them and those sold by the local remanufacturer; i.e., the brand is more important. This is true of many items, like single-use cameras and printer toner cartridges, where many OEMs themselves do not distinguish between new and remanufactured items.*
>
> (Majumder and Groenevelt, 2001a, p.129)

Majumder and Groenevelt (2001a) also seem not to distinguish between the re-use of empty toner cartridges or camera cases and a remanufacturing operation as it has been defined earlier in this chapter. However, it must be noted that the discussion on remanufacturing models (Section 2.5.3) has demonstrated that remanufactured products

are, in most cases, not regarded as equivalent to new goods, despite them meeting or even exceeding quality standards for new products. Hence, remanufactured products are destined for a secondary market. As a result, the position taken by Majumder and Groenevelt (2001a) is too general and may only be applicable to certain industry sectors, but not to the automotive industry. Ferrer and Whybark (2001) confirm that in the automotive sector, consumers clearly differentiate between new products which are destined for vehicle assembly and remanufactured products, which are exclusively distributed as spare and replacement parts (aftermarket).

This research therefore seeks to address the shortcomings of previous research. A case study approach is taken in order to obtain empirical data. Van der Laan *et al.* (2003) confirm that more case studies are necessary to bridge the gap between theory and practice. They furthermore admit that there is limited applicability of current, theoretical models. However, as they have previously confirmed, there is at least an interest from the scientific community that makes this field worth studying. An overview of key contributions, focusing on (in-plant) remanufacturing issues is given in Tables 4 and 5. This dissertation therefore seeks to complement and extend existing research.

Summary

Process Step	Author(s)	Approach	Problem(s) addressed	Results
Core return and acquisition	Ferrer (2001)	Mathematical modelling (MRP logic)	▪ Uncertainty of core supply ▪ Uncertainty of good parts in cores ▪ Uncertain demand for remanufactured goods	▪ Development of a model to manage supply and demand
	Toktay *et al.* (2003)	Mathematical modelling (forecast model)	▪ Uncertain timing of product returns	▪ Development of a model to forecast returns
	Guide *et al.* (2003b)	Mathematical modelling (economic model)	▪ Variations in quantity, quality and timing of returns	▪ Development of a model to improve product acquisition and profitability
Disassembly	Lambert (2003)	Survey (literature review)	▪ Product disassembly sequencing	▪ Overview of existing research on disassembly
	Langella (2003)	Mathematical modelling (heuristics) and numerical examples	▪ Disassembly planning ▪ Disassemble-to-order ▪ Parts complexity	▪ Development of a model for core procurement, holding and disposal while meeting demand
	Ketzenberg et al. (2002)	Mathematical modelling and simulation	▪ Design of a mixed assembly-disassembly line	▪ Development of a model that supports decisions on buffer holding in an assembly-disassembly environment
	Taleb and Gupta (1997)	Mathematical modelling	▪ Multiple product structures	▪ Development of two algorithms which support disassembly
	Ferrer (2001)	Mathematical modelling and numerical experiments	▪ Design for disassembly ▪ Design for recycling ▪ Design for re-use	▪ Model to support the decision-making process whether to recover a certain part; hereby considers its wear state ▪ Emphasises the importance of design-for-environment

Table 4: Quantitative Approaches to Problem-Solving within Remanufacturing Operations – Part 1

Process Step	Author(s)	Approach	Problem(s) addressed	Results
Recovery planning and control	Kiesmüller *et al.* (2003)	Mathematical modelling	▪ Controlling of dynamic product recovery	▪ Development of a solution methodology for optimal recovery policies, including capacity constraints and multiple re-use options
	Guide *et al.* (2003a)	Case study	▪ Examining factors which impact production planning	▪ Production planning and control has to be tailored for individual cases; 'one-size-fits-all' approaches tend to fail
	Guide (2000)	Survey (questionnaire)	▪ Uncertainty of core returns ▪ Imbalances of return and demand rates ▪ Uncertainty of core condition	▪ Identification and discussion of seven complicating characteristics within remanufacturing
	Inderfurth and Teunter (2003)	Survey (literature review)	▪ Planning and scheduling issues ▪ Materials planning ▪ Shop floor control	▪ Outlining research findings which have addressed the seven complicating characteristics identified by Guide (2000)
Inventory control	Mahadevan et al. (2003)	Mathematical modelling (heuristics) and simulation	▪ Decision problem when to transfer cores to the recovery line ▪ Identification of the number of new products to be manufactured	▪ Development of a remanufacturing push inventory system
	De Brito and Dekker (2003b)	Survey (literature review) and data analysis	▪ Assessment of general assumptions	▪ There is the need to amend 'traditional' assumptions to match real-world issues and cases
	Van der Laan (1997)	Mathematical modelling and case study	▪ Push and pull control with and without disposal	▪ Identification of an appropriate production planning and inventory control model for remanufacturing
	Toktay et al. (2000)	Mathematical modelling (heuristics)	▪ Procurement of new components	▪ Identification of an optimal ordering policy, in order to reduce inventory holding costs

Table 5: Quantitative Approaches to Problem-Solving within Remanufacturing Operations – Part 2

2.6 Conclusion

This chapter has identified key definitions within closed-loop supply chain management. Moreover, the chapter has set the scientific framework for research in the area of closed-loop supply chain management. It has outlined the different understandings of product recovery operations, while emphasising remanufacturing. An industry-specific product recovery framework was developed.

In addition, the chapter has discussed current closed-loop supply chain structures and the assumptions contributors take in designing these. It became clear that previous closed-loop supply chain models could not be directly applied to the automotive sector. The critique of generic closed-loop supply chain structures has led to the development of Research Question 1, which aims to characterise the typical closed-loop supply chain structure for automotive remanufacturing.

Moreover, generic remanufacturing process structures have been discussed in this chapter. These models, however, lacked in detailed process data, for example. As a result, Research Question 2 was generated, which aims to identify a model of an automotive remanufacturing process to which 'real world' process data is added.

Section 2.5 portrayed the historical development of automotive remanufacturing, the main players in the remanufacturing sector and also discussed the main issues of uncertainty within remanufacturing. Different quantitative approaches to problem-solving have been outlined and general criticism of these has been pointed out. This has led to the conclusion that the assumptions of previous quantitative work in the field need to be adapted, in order to create more suitable models for real-world situations. This thesis therefore seeks to support the redefinition of such assumptions by providing an in-depth and industry-specific understanding through empirical research. Chapter Four will further justify the decision for enquiry.

While this chapter has taken a supply chain perspective on automotive remanufacturing, the following chapter will review literature on the environmental side of automotive closed-loop supply chain management. Together, these two perspectives seek to provide a comprehensive, interdisciplinary picture of automotive remanufacturing.

Chapter Three
Main Debates in the Environmental Social Sciences

3.1 Introduction

This chapter consists of two parts. Firstly, it seeks to demonstrate that there is a lack of theoretical grounding for research on closed-loop supply chain management. Moreover, it justifies the needs for finding and developing an appropriate theory for closed-loop supply chain management. Secondly, through the review and discussion of theories from related fields, this chapter aims to identify elements within these theories, which may provide the first steps in the theory-building process for closed-loop supply chain management. Chapters Nine and Ten will further continue this discussion by assessing the potential elements that theories from related fields could provide to explain the observed phenomena.

In the second part of this chapter, the main motives for corporate environmentalism will be discussed. These motives have been partly derived from the first, theoretical part of the chapter, but also from the rather specific literature on reverse logistics and closed-loop supply chain management. The second part will demonstrate how ethical responsibility, environmental legislation or a direct economic motive could induce

automotive remanufacturing. The discussion results in the creation of three further research questions for this dissertation.

3.2 Theoretical Considerations

3.2.1 The Lack of Appropriate Theory and its Impact on this Research

A theory is defined as "[...] a coherent set of general propositions, used as principles of explanation of the apparent relationships of certain observed phenomena" (Zikmund, 1994, p.20). In other words, a theory is a set of statements or claims with regard to a certain phenomenon (generic behaviour), which is seen as valid after being tested throughout a number of cases (Keating, 1995). Van den Ven (1989) emphasises the relevance of a good theory for any scientific research, since it advances knowledge, but also guides research into the right direction. With regard to operations management, Amundson (1998) argues that this discipline lags behind other disciplines, such as sociology and economics, in the creation of theory.

There are several reasons for this. On the one hand, Amundson (1998) perceives that there are fewer active researchers in the field of operations management, compared to other disciplines. Moreover, theory-building has not been seen as a central component within operations management, whereas other disciplines, particularly disciplines from the social sciences, have traditionally focused on the study of theory (see, for example, Glaser and Strauss, 1967; Charmaz, 1983; Strauss and Corbin, 1994). Closed-loop supply chain management, too, lags behind other disciplines with regard to theory building. This fact is particularly true, since closed-loop supply chain management is only represented by a short research history.

Chapter Two has demonstrated that the area of closed-loop supply chain management is still fairly young. The earliest contributions on reverse logistics were made in the early 1990s. Publications on closed-loop supply chain management followed in the late 1990s (see Section 2.2.3). Various authors in the area of reverse logistics, product take-back and recovery have criticised the lack of a theory or the absence of a theoretical

framework for research in this field (e.g. Handfield *et al.*, 1997; Carter and Ellram, 1998; Van Hoek, 1999; Dowlatshahi, 2000). According to these contributors, there is no appropriate theoretical grounding for research in this area. Hence, they have expressed the need for research that contributes to theory-building.

Handfield *et al.* (1997) explain that a development towards a 'greening' of logistics and supply chains is a logical extension of process-focused programs aiming at the reduction of all types of waste (e.g. Total Quality Management). However, a grounded theory for this new phenomenon is lacking due to a simple reason. "Because the academic research focus on these environmental issues is relatively new, little prior theory exists in which to ground testable hypotheses concerning the role of environmental management in the operations management value chain" (Handfield *et al.*, 1997, p.294). However, the theory-building process is essential to distinguish scientific knowledge from common sense (Reynolds, 1971). Handfield and Melnyk (1998) further confirm the importance of theory for any research and argue that empirical research becomes 'data dredging' without a theory. Consequently, "[...] data, whether qualitative or quantitative, characterize; theory supplies the explanation for the characteristics. Therefore, we must make sure that what is passing as good theory includes a plausible, cogent explanation for why we should expect certain relationships in our data" (Whetten, 1989, p.491). According to Whetten (1989), an initial, rudimentary theoretical statement consists of three elements.[6] The first element comprises the factors of the theory, such as variables, constructs and concepts, in other words, the *'what'* aspect of the theory. Moreover, there is the *'how'* element of the theory, which presents how these factors are related. This step includes the delineation of patterns and searches for causality (Whetten, 1989). The third element investigates underlying psychological, economic or social dynamics and may therefore be perceived as the 'glue' of the theory, since the *'why'* aspect explains, whereas the previous elements (*'what'* and *'how'*) describe (Whetten, 1989).

[6] In his article, Whetten (1989) refers to previous 'theory-development authorities' and therefore to four essential elements a *complete* theory contains. However, the aim of this dissertation is not to develop a complete theory for closed-loop supply chain management, but to provide the first elements to what may later develop into a complete theory. The author therefore only refers to the three elements, which Whetten sees as essential to an *initial, rudimentary and theoretical statement.*

Van Hoek (1999) confirms the lack of a grounded theory, as it has already been pointed out by Handfield *et al.* (1997): "[...] literature on the role of supply chain operations, mostly published in the area of reversed logistics, has failed to develop grounded theory and frameworks to support the application of such an approach" (Van Hoek, 1999, p.129). He therefore recommends two needs for research. First of all, future research has to go beyond the limited perspective of reverse logistics. Hence, a holistic view is required, which includes the entire (green) supply chain rather than reverse logistics only.

Secondly, more work is required with regard to the development of a theoretical framework for research on green supply chains. This dissertation will therefore exactly focus on these two points. On the other hand, this research does not aim to test theories or hypotheses, since the previous step, the theoretical grounding, still seems to be absent. In contrast, the research questions within this thesis seek to establish and provide ideas and concepts which assist in the development of a grounded theoretical framework for closed-loop supply chain management.

However, there are contributors who argue that one of the main weaknesses within operations management research is the belief that there is no appropriate theory. These contributors also criticise that the alleged lack of an appropriate theoretical framework is often used as justification for the application of case study strategies.

> *The rationale behind using cases as a research method in OM is no exception.* [...] *a major weakness of OM researchers in this first stage is the presumption that applicable theory does not exist. Contributing theories may well exist outside OM's traditional boundary.*
>
> (Stuart *et al.*, 2002, p.423)

These authors therefore recommend assessing theories in related fields, such as marketing, manufacturing or finance, which may result in the application of these theories or parts of the theories in other disciplines, such as operations management. This chapter therefore reviews theories, concepts and debates from the environmental social sciences, in order to evaluate whether these could be applied to closed-loop

supply chain management. The aim is to identify elements within theories which may potentially provide basic ideas to create the first steps for a closed-loop supply chain management theory.

> *Advances in other disciplines can provide a much-improved starting point for defining the appropriate research question. The research question and the state of knowledge define if and when a case-based research approach is appropriate (or even necessary). Failure to adequately assess the advancement of knowledge in related fields is a fatal research process error.*
>
> (Stuart *et al.*, 2002, p.423)

The reasons for investigating theories and concepts from the environmental social sciences as opposed to theories from related business studies (as Stuart *et al.* have suggested), are justified as follows. Firstly, contributors in the area of closed-loop supply chain management and remanufacturing research have generally not sought to investigate theories from the environmental social sciences. Theories which were consulted by previous research narrowly focused on the remanufacturing operation itself, rather than the whole closed-loop supply chain. Examples include inventory control theory (e.g. Van der Laan, 1997; Van der Laan *et al.*, 2003; De Brito and Dekker, 2003b), contingency theory (e.g. Guide and Van Wassenhove, 2002a) or repairable inventory theory (e.g. Schrady, 1967; Guide and Srivastava, 1997). However, as Van Hoek (1999) has pointed out, there is the need for a holistic approach. Hence, a theoretical framework for closed-loop supply chain management as a whole is required.

Secondly, the increasing formulation of product take-back and recovery regulations, as for example in Europe (e.g. CEC, 2000, 2002c), seems to demand for a consultation of ideas from an environmental area of research. Thirdly, the automotive sector has often been targeted by environmental legislation, as this chapter will further demonstrate.

3.2.2 Sustainable Development

The sustainability approach seeks to combine the present industrial development with the requirements of future generations (Wilkinson *et al.*, 2001). In 1987, the Brundtland Commission defined the term 'sustainable development' as the development that "meets

the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p.43). This definition comprises two concepts. Firstly, there is the concept of 'needs', which represents the essential needs of the poor. Secondly, there is the idea of 'economic limitations', so that future generations will be able to meet their own needs. Allenby (1999) claims that, to date, existing data does not prove or disprove that the current economic development compromises the ability of future generations to meet their needs. However, sustainability implies a redistribution of wealth from current to future generations and from developed to developing nations. It also suggests the aggressive restriction of population growth (Allenby, 1999).

Concerns that future generations may not be able to meet their needs are not at all new. Early contributors, such as Thomas Malthus (1766-1834), have yet discussed the effects of population growth and food supply (Robinson, 2002). Today, the concept shows more facets than securing food supply. The sustainable development concept may be seen as the all-embracing idea and umbrella of theories such as industrial ecology. Isenmann (2003) defines industrial ecology as the 'science of sustainability'. Hence, sustainability may be seen as the superior concept for theories in the environmental social sciences. But still, since the concept of sustainability has not been around long enough, problems of its definition occur (Smith, W., 2002). One of the problems to identify may be the breadth of the concept, which seeks to include a variety of areas and tries to accomplish a large diversity of objectives. "Nevertheless, despite the diversity of interpretations, most supporters of sustainability agree that it involves a fundamental concern for the health of the physical environment, economic prosperity, and social wellbeing, and achieving a balance in these objectives over time" (Smith, W., 2002, p.14). Hence, the concept of sustainability comprises four dimensions, the social, the economic, the environmental and the institutional dimension (Smith, W., 2002). However, the breadth of the concept complicates the operationalisation and achievement of individual goals or milestones. Graedel and Allenby (1998) illustrate that the vision of a 'sustainable development' is worthy and necessary, but ambiguous and too broad to operationalise. In their eyes it is therefore necessary to break this vision down into smaller concepts, such as industrial ecology. Hereby, industrial ecology is perceived as

a multidisciplinary study of industrial and economic systems and their interrelations with natural systems (Graedel and Allenby, 1998).

Overall, the notion of sustainable development is not static, but rather an idea that comprises change over time, as the term 'development' reveals. The emissions of greenhouse gases, which cause global climate change, the establishment of sustainable transport, as well as the careful management of natural resources, are all aspects which need to be addressed on a business scale. The changes which are required within business operations are therefore particularly relevant with regard for this research. For businesses, achieving sustainability is generally perceived as painful (e.g. reducing the exploitation of resources). Consequently, sustainable development seems to be rather unpopular among businesses (Holliday, C.O. *et al.*, 2002). Hutchinson (1996) argues that companies should take a leading role with regard to this agenda for change, since they may influence employees to re-examine their values and involve staff to re-focus the corporate mission as well as the company objectives.

According to Holliday, C.O. *et al.* (2002), companies also require to understand that the need for change is not working against their growth. Instead, sustainability may even prevent corporate failures, the authors explain. Corporations focusing on short-term objectives, for example, may not notice essential technologies. The automotive industry and the automotive supply chain seem to be rather active with regard to sustainability (Boons and Baas, 1997). Further improvement seems to be required with regard to automotive consumption, such as the reduction of auto use (World Business Council for Sustainable Development, 2001). However, this discussion will not be part of this thesis.

3.2.3 Industrial Ecology

The roots of what is nowadays known as industrial ecology began with reference to the term ' metabolism' and can be found in various other disciplines, such as biology, biochemistry or physiology. In the middle of the 19th century, the term metabolism was first applied to society (Fischer-Kowalski, 2002), while in the 1960s, the discussion was extended onto the modern industrial society, with Wolman (1965) and Ayres and

Kneese (1969) making the first contributions. With regard to the contemporary industrial systems, Graedel and Allenby (1998) explain that the concept of industrial ecology deals with the interactions of society, industry and the environment. Industrial ecology is therefore defined as:

> *...the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimise the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.*
>
> (Allenby, 1999, p.40)

As a result, industrial ecology may be described as the industrial perspective of sustainable development. In other words, the concept is embedded within the idea of sustainable development, but focuses on industrial action without denying or ignoring the importance of other subsystems of sustainability. As described in the above definition, industrial ecology investigates the total materials cycle from cradle to grave. However, unlike the above definition says, the aim of industrial ecology should be the recovery of any obsolete or end-of-life product (closing the loop), rather than its disposal. Hence, if industries seek to close an endless, repetitive materials cycle, an extension of the above definition is necessary, as for example suggested by Frosch and Gallopoulus (1989). In other words, 'ultimate disposal' in the above definition should be replaced by 'the return of obsolete products for recovery'. "A critical element of industrial ecology, in fact, is to understand how economic systems can be evolved so that materials do not simply pass through the economy in a linear fashion and become waste [...], but are cycled within the economy to the greatest practicable extent [...]" (Allenby, 1999 p.133).

The central theme within the discipline of industrial ecology is the idea of taking the ecology as a blueprint for designing sustainable business strategies, or the so-called 'eco-mimicry' (Anonymous, 2001). Bourg (2003) describes this phenomenon as taking

the lessons from natural metabolism in order to artificially form an industrial metabolism. However, there is an ongoing debate among contributors, whether the natural ecology can be used as a template for conducting business. Bill Shireman, one of the main contributors in this field, explains why this idea can work.

> *Industrial ecologists define industrial ecology as the application of ecological principals to business, looking at business as a living system. We see business as a living system that is composed of people who are themselves living systems. Businesses are also communities; they adapt, they evolve, and they show those characteristics of living principles. So we say that if it works for nature, it can work for business.*
>
> (Bill Shireman in Anonymous, 2001, p.19)

It is difficult to judge if these principles are applicable to current industrial systems in general, and to the automotive industry in particular. The sensible use of resources ('maintaining a carrying capacity') seems rather unlikely in a world determined by egoism, consumption and (industrial) competition. According to the classic capitalist viewpoint, corporations are driven by profit maximisation (see also Section 3.4.2). This indicates that companies may not include the 'maintaining of a carrying capacity' into their agenda. Attempts have been made in the automotive sector, an industry that is well known for its intensive use of virgin materials (Wells and Nieuwenhuis, 2001). Therefore, the closure of the automotive loop still seems to represent a challenge. "In some cases there is potential for a feedback of recyclate into the automotive value chain, though not necessarily for the same purpose (for example, only an estimated 60% of 'new' steel and 65% of 'new' aluminium are actually virgin material [...]). At present, however, most vehicular material other than metal is landfilled – apart from liquid wastes" (Deutz, no date given, p.3).

John Harte, a major contributor in the area of industrial ecology therefore questions the key-point of taking nature as a blueprint for industrial action. In his eyes, natural ecosystems are too complex and cannot be applied to businesses. One of the reasons why nature does not always provide a good template for industry is the fact that some examples just work on a global scale, such as the recycling of carbon (Anonymous, 2001). Moreover, the environmental system is relatively unstable. Industry and

economy, however, ask for stability. Instead of taking the insights of ecology as a blueprint or template for designing sustainable business, John Harte therefore suggests the second approach known to researchers in this area. It implies the thinking in terms of lessons systems can learn from the natural ecology (Anonymous, 2001). John Harte therefore concludes:

> *In summary, nature is hardly a template for how an industrial society should work. Applied to human society, what nature does is impractical for us to copy on a global scale, and wasteful, unstable, and sometimes even unethical for us to try to mimic on a local scale. However, nature does impose boundary conditions on our behavior. We can ignore these constraints and live off of declining ecological capital for a while, but in the long term, we are going to have to adapt to nature's limits. If we don't adapt, we risk extinction – if not of our species, of our civilization.*
>
> (John Harte in Anonymous, 2001, p.19)

With regard to this dissertation, industrial ecology may provide elements to the development of a theory for closed-loop supply chain management. It could also provide explanations for phenomena that are observed within the research. As outlined previously, data characterise, but only theory provides explanations for these characteristics (Whetten, 1989). Consequently, the question arises, which elements industrial ecology may provide for a better understanding of the phenomena that will be discovered within closed-loop supply chain management and remanufacturing in the automotive sector.

Firstly, industrial ecology theory provides and explains one of the main ideas behind closed-loop supply chain management. As Chapter Two has demonstrated, one of the ongoing discussions within the closed-loop supply chain management literature evolves around the total closure of the supply chain. The idea that waste of one industrial process serves as raw material to another process originates from industrial ecology ('metabolic thinking'), but can be found in the emerging field of closed-loop supply

chain management.[7] Chapter Two has pictured various closed-loop supply chain models, which all incorporate the idea of the endless, repetitive product or materials cycle with limited waste.

Secondly, academic contributions within the field of industrial ecology inform closed-loop supply chain management research. A good case in point is the publication by Graedel *et al.* (2002), who picture the complete life cycle of an automotive vehicle from raw material extraction to end-of-life. Their perspective is narrowly based on material flows. The contributors have correctly identified that remanufactured parts return for customer use (vehicle in use), rather than to the point of manufacture as many researchers in closed-loop supply chain management assume. The only point of criticism with regard to their work is the fact that a core for remanufacturing does not necessarily originate from a retired car, but could also come from a car in use. However, the material flow perspective which is often applied within industrial ecology research assists with the correct identification of material and product flows, rather than providing idealised conceptual models, as for example by Thierry *et al.* (1995). Closed-loop supply chain management has traditionally focused on the product flows along the supply chain, the actual recovery processes, as well as the relationships between companies involved in the management of the closed-loop supply chain. In this way, industrial ecology thinking and closed-loop supply chain management may complement each other. Closed-loop supply chain management provides a whole account of the supply chain, whereas industrial ecology focuses on the detailed description of material flows.

Thirdly, industrial ecology provides an extensive set of tools which could be used for measuring and analysing material and product flows along the closed-loop supply chain. These tools include, for example, life cycle analysis, material flow analysis and physical

[7] Frosch and Gallopoulus (1989) have defined this idea as 'industrial ecosystem', which functions similar to a biological ecosystem. In other words, plants produce nutrients for herbivores; herbivores represent feed for carnivores; the wastes and bodies of carnivores nurture new plants.

input-output accounting (see Ayres and Ayres, 2002).[8] Previous researchers, such as Linton *et al.* (2002) and Geyer and Jackson (2004) have applied these tools to research issues in remanufacturing, recycling and reuse, respectively. Publications, such as by Allen (2002), show a very specific material flow analysis of waste as raw-material. The compilation and analysis of material flows may seem very much focused on the chemical composition, however, such tools and knowledge may inform closed-loop supply chain and product recovery management in various ways. On the one hand, from a supply chain perspective, it may be measured whether product take-back processes (reverse logistics; transport) are more harmful in environmental terms than landfill. On the other hand, a detailed material flow analysis may be produced for the recovery processes. These could be described as 'eco-balance sheets' and could demonstrate the environmental impacts of remanufacturing, for example. Input and output measurements could also help to indicate waste streams within remanufacturing or to discover inefficiencies within the recovery process. This dissertation, however, will not apply such methods, since the research problem explores closed-loop supply chain structures and motives for product take-back, rather than quantifying material inputs and outputs. However, the tools and techniques applied within industrial ecology research may be beneficial for further research on automotive remanufacturing.

Finally, this dissertation aims to investigate how industrial ecology theory may explain the phenomena occurring in this research (see Chapters Nine, Ten and Eleven). In addition, not merely a feedback from industrial ecology theory to this research on automotive closed-loop supply chain management is sought to be developed. This research also aims to inform industrial ecology theory by providing a specific industrial example of automotive remanufacturing. By providing this specific example, the research demonstrates which ideas from the literature can be transformed into practice in the 'real-world' and which ideas may not be applicable. As a result, future research in the area of industrial ecology may become more specific, including real-world assumptions and the discussion of issues and obstacles that are relevant to industry.

[8] Life cycle analysis has been defined as a technique to measure and assess a product's environmental aspects and impacts by compiling the inputs and outputs of a system (De Haes, 2002).

3.2.4 Systems Thinking

General systems theory firstly emerged from the work by Köhler (1924) and was further developed by Von Bertalanffy (1968) and Boulding (1956), who suggested that an organisation should be seen as a set of integrated components, each with a certain purpose. A system can therefore be understood as an accumulation of parts forming a unitary whole (Johnson *et al.*, 1973), or 'a set of interrelated elements' (Ackoff, 1971). In other words, the understanding of a system includes the wholeness, its formation out of elements and the interaction between those elements. With regard to supply chain management, systems thinking has influenced the discipline by 'thinking of the whole', rather than of individual aspects. "It is necessary for managers to begin to think in terms of total systems rather than of narrow functional areas" (Christopher, 1986, p.8). This can be interpreted in two different ways. On the one hand, specific functional areas within one organisation should not be seen in separation from the other functional areas in the same organisation. On the other hand, it may be argued that a systems approach aims to understand the whole supply chain and the interaction of the supply chain echelons, rather than focusing on one organisation only.

General systems theory, however, is not only concerned with how an organisation operates, but it also seeks to investigate the interaction between an organisation and its environment. A distinction can therefore be made between open and closed systems. Closed systems operate independently from the environment and without outside influence; open systems describe an interaction between the organisation and the outside world (Hodge and Anthony, 1991). These definitions are based on the work by the physicist Köhler (1924, 1938), who observed systems that interacted with their environments and therefore called them 'open systems'.

Checkland (1999) further differentiates between 'hard' and 'soft' systems thinking. The major difference between hard and soft systems is the observer's perception of the world: a hard systems thinker assumes that the world contains accounts of wholes, therefore taking the world as 'holonic', whereas a soft-systems thinker holds the view that the methodology (process of enquiry) itself is created as an account of the whole (Checkland, 1999). In other words, the 'hard' engineering tradition aims to change the

system while taking the problem as given. 'Soft' systems thinking, on the other hand, compares the conceptual models with the current state in the real world in order to identify feasible changes that could eliminate the problem (Checkland, 1981).

Systems theory is relevant to this research for two reasons. Firstly, it shares common roots with industrial ecology theory. Boulding (1966), for example, refers to the work by Von Bertalanffy (1952). Key contributors within industrial ecology, such as Allenby (1999), argue that the understanding of complex economic systems is an essential element of industrial ecology. In addition, Section 3.2.3 has outlined that industrial ecology applies tools that are similar to the methods used within research that takes a systems perspective (input-output models; systems modelling). The critical need for a systems perspective within industrial ecology is also emphasised by Lifset and Graedel (2002). In their eyes, systems thinking can be found within industrial ecology due to the life cycle perspective that is adopted and the material and energy flow analyses that are applied within contributions in the field of industrial ecology. Definitions of the term industrial ecology, such as the one by Allenby (1999), refer to a 'systems view', 'industrial systems' as well as 'surrounding systems' and the optimisation of resources, energy or capital. Moreover, both theoretical perspectives incorporate elements of 'efficiency' and 'optimisation', with regard to materials, capital, energy or processes, for example.

Secondly, in this dissertation, a systems approach assists in the understanding of the closed-loop supply chain as a system, its composition of individual elements (companies; supply chain echelons) and the interaction between these elements. Hence, it may be claimed that this research has adopted a 'soft' systems approach, since the process of enquiry aims to investigate the remanufacturing closed-loop supply chain as a whole. Moreover, systems thinking provides the definitions for open and closed systems, an aspect which has only been marginally investigated by previous research, such as by Fleischman *et al.* (2000).

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3.2.5 Corporate Social Responsibility

Although there is no theory on corporate social performance as such, corporate social responsibility has been of interest within academia for decades (Wood, 1991). Carroll (1999) demonstrates how the understanding of corporate social responsibility has changed within the past fifty years. In the 1950s contributors saw corporate social responsibility (CSR), which was then often referred to as 'social responsibility', as the responsibility that was taken on by business executives for the impacts of their actions beyond the profit-and-loss statement. This understanding of CSR has been slightly changed in the 1960s, where it was expected that social power and social responsibility should be in equilibrium (Carroll, 1999). In the course of time, definitions became more specific, with Carroll developing a very comprehensive understanding of CSR in 1991.

> *For CSR to be accepted by the conscientious business person, it should be framed in such a way that the entire range of business responsibilities is embraced. It is suggested here that four kinds of social responsibilities constitute total CSR: economic, legal, ethical and philanthropic. Furthermore, these four categories or components of CSR might be depicted as a pyramid. To be sure, all of these kinds of responsibilities have always existed to some extent, but it has only been in recent years that ethical and philanthropic functions have taken a significant place.*
>
> (Carroll, 1991, p.40)

Carroll (1991) hereby sees the economic responsibility ('be profitable') as the basis for all other responsibilities. Hence, in order to 'obey the law', 'be ethical' and 'be a good corporate citizen', the financial security is absolutely necessary (Carroll, 1991). Corporate social responsibility is therefore seen as a concept in which a corporation is responsible for the impact of its actions. However, it does not ignore the necessity of a sound financial basis, which is essential for further steps, such as the extension towards an ethical and philanthropic responsibility.

Having discovered that an increasing number of European companies are promoting their strategies with regard to corporate social responsibility, the European Commission developed a Green Paper in order to present a consistent European framework. The Commission distinguishes between the internal and the external dimension addressed by

CSR. The internal dimension comprises all aspects occurring within a corporation, such as human resources management, health and safety at work, adaptation to change and the management of environmental impacts and natural resources. The external dimension concerns the company's relationship to the society. It includes the local communities, business partners, suppliers, consumers, human rights as well as global environmental concerns (CEC, 2001b). Most relevant to this research are the environmental elements of CSR: the Integrated Product Policy (IPP) and Environmental Supply Chain Management (ESCM), as identified by Williams (2003). Integrated Product Policy takes a life cycle approach and aims to reduce the environmental impacts of products and services within this cycle (CEC, 2001c). Environmental Supply Chain Management, on the other hand, is simply seen as the 'greening' of the supply chain, which has already been discussed in Chapter Two.

This section, however, needs to emphasise the ideas behind a corporation seeking to be more ethical and 'a good corporate citizen'. Bansal and Roth (2000) explain that corporate environmental performance may be driven by ethical motives. Klonoski (1991) discusses whether corporations could be seen as morally responsible for their actions and if they may be identified as 'moral agencies' or 'moral person'.[9] Consequently, the discussion therefore evolves around the question to what extent companies undertake environmental actions, because they seek to be morally or ethically responsible. This is the case, if firms feel responsible for their role in society and therefore transform the company's activities into environmentally friendly business processes. Den Hond (1996) categorises the ethical motives as firm-specific factors, where the executive management aligns its vision with respect to environmental protection. Yet, there are examples of corporations which are entirely based on this motive, such as the *The Body Shop* company (e.g. Saunders, P, 2003). Bansal and Roth (2000) further describe the concern for the social good as a motive for ecological and corporate responsibility.

[9] The perspective of classifying a company as moral agency or moral person is particularly supported by the American philosopher Peter French (e.g. French 1990).

Environmentalism and its public awareness have been characterised as the most significant forces, which shape the current economy (Murphy *et al.*, 1994). Environmentalism has also been identified as one of the most important issues which businesses face since the beginning of the nineties. The general society has been perceived as a major impact factor for corporate behaviour. This motive has been described as 'legitimation' by Bansal and Roth (2000) and specifies that corporations may engage in sustainability measures to be accepted by society. However, Hart (1997) notes that eco- friendly corporate performance is still implemented through a reactive approach by avoiding sanctions rather than a proactive effort to support environmental behaviour. It therefore may be rather difficult to identify if corporations promote their corporate social responsibility based on 'true' ethical reasons, or if they are driven by 'disguised' motives. In other words, a company may claim to 'be a good corporate citizen', but aims to generate positive, non-monetary effects by these actions. Elkington (1994) has already pointed out the important role the consumer plays in this discussion. He reports on a survey conducted in 1992 and in 22 countries, which reflects the public opinion of 22,000 citizens. One of the key findings was the respondent's universal belief that individual action is worthwhile and helps to protect the environment. Those actions could, for example, comprise 'green consumerism', which is characterised by the avoidance of products that are harmful to the environment. More than a quarter of respondents in each country claimed to have acted as 'green consumer' in the year 1991 (Elkington, 1994). Hence, Elkington (1994) argues that the creation of a 'green marketplace' or the 'greening of the marketplace' is very much inspired by actions, such as green consumerism. He furthermore explains that consumers have hereby acted in a completely unexpected manner. However, their strategic position as citizens, voters, consumers and employees should not be neglected. "'Ethical' or 'global' consumers will, we believe, help to drive demand for dramatically improved standards of corporate citizenship" (Elkington, 1994, p.92).

There is a second perspective to the crucial role of the consumer within corporate social responsibility in the form of competition for consumers. According to Burke and Logsdon (1996), an increase in competition within industry puts pressure on firms. They explain that "tougher competitive conditions in recent years have put pressure on firms to examine their philanthropy and other social responsibility activities" (Burke and

Logsdon, 1996, p.495). Consumer pressure has been identified by Lamming and Hampson (1996) as motivational factor for improving business processes in environmental terms. In their eyes, the consumer's purchasing decision is influenced by the company's environmental performance, hence consumers are willing to pay higher prices for environmentally friendly goods. This argument is supported by Van Hoek (2002). According to Krikke (2001), consumers likewise expect the producers to take back old machines when they wish to dispose of them. This may further influence their buying processes. Bansal and Roth (2000) even claim that stakeholders in general are playing a major role in provoking corporate ecological responsiveness. Image enhancement is strongly linked with the aspect 'consumer pressure'. Due to the fact that there are consumers, which appreciate a return service for used products or an environmentally friendly behaviour of companies, organisations now accentuate reverse channels in their marketing campaigns. Furthermore, the 'greening' of supply chains is used in marketing initiatives, in order to affect a company's image positively (Van Hoek, 2002). The image enhancement might even result in a competitive position (Den Hond, 1996) or in improved revenues (Bansal and Roth, 2000). Holliday, C.O. *et al.* (2002) summarise: the "three key benefits of CSR are brand value and reputation, improvements in human capital and revenue generation, particularly in large and as yet undeveloped markets" (p.112). However, it seems difficult to judge the level of a company's corporate social responsibility. Actions on a 'voluntary basis' indicate that they need to go beyond the level required by law. However, the legal framework changes from one country to another.

The research question which develops from the above discussion is therefore based on the assumptions which have been made by previous contributors. These include that firstly, industrial ecology theory assumes that humanity seeks to maintain (deliberately and rationally) a 'desirable carrying capacity' (Allenby, 1999). The corporate social responsibility concept adds that a company is (morally or ethically) responsible for the impacts of its actions (e.g. French, 1990; Klonoski, 1991). As main reasons for being socially responsible, contributors have listed 'green consumerism', the 'green marketplace' (e.g. Elkington, 1994) and competition (e.g. Burke and Logsdon (1996). Literature on reverse logistics and product recovery has also noted the commitment to

environmental issues, ethics or producer responsibility as reasons for undertaking reverse logistics and product recovery.[10]

The combination of these assumptions which were filtered from industrial ecology theory, the concept of corporate socially responsibility and the specific literature on product return and recovery management are therefore tested within this research.[11] The main objective is to discover whether these assumptions are valid for the automotive remanufacturing sector.

Is automotive remanufacturing induced by a corporation's needs to be morally or ethically responsible for its actions? (Research Question 3)

[10] See, for example, Kopicki *et al.* (1993); Fleischmann *et al.* (1997); Carter and Ellram (1998), Dowlatshahi (2000), Ferrer and Whybark (2000), Klausner and Hendrickson (2000).
[11] A summary of the relationship between sustainability and industrial ecology, the main ideas of the concepts and how these can be achieved is given in Appendix C.

3.3 Remanufacturing: Contribution towards Sustainability?

Guide and Van Wassenhove (2001) state that producer responsibility legislation has become increasingly popular. On the one hand, product life cycles are decreasing, leading to a large number of used products entering the waste stream. The disposal of these products presents a considerable environmental burden. On the other hand, these products may also serve as raw material for recovery operations (Guide and Van Wassenhove, 2001). This section of the chapter seeks to examine the (potential) contribution remanufacturing makes with regard to sustainability. It questions the ability of product remanufacturing to satisfy customer demand while contributing towards a sustainable behaviour. Steinhilper (1998) points out that this dual-purpose is one of the reasons for an increasing interest in this particular recovery operation.

Consequently, there is the need for a discussion on the contribution remanufacturing may make to each of the dimensions of sustainable development, as suggested by Smith, W. (2002), the social, the economic, the environmental and the institutional dimension. Spangenberg and Bonniot (1998) suggest a range of performance indicators to measure sustainability:

- **Environmental indicators**: Resource use (extraction), state indicators
- **Social indicators**: Health care, housing, social security, unemployment
- **Economic indicators**: Gross National Product (GNP), growth rate, innovation, competitiveness
- **Institutional indicators**: Participation, justice, gender balance

3.3.1 Social and Economic Contribution

Lund (1996) claims that there is a lack in public awareness regarding the large contribution the remanufacturing industry makes towards the overall social and economic performance. The remanufacturing sector employs a large number of people, generates tax power and furthermore supplies the market with low-priced durable

products (Lund, 1996). Steinhilper and Hudelmaier (1993) assume that approximately 10,000 employees in Germany and 200,000 worldwide work in the remanufacturing sector (figures from 1993). In 1996, Lund (1996) estimated the total direct employment of the US remanufacturing sector to be approximately 480,000. For the UK, Parker (2003) assumes that the whole remanufacturing sector employs approximately 50,000 people. However, even industry experts struggle to quantify the attributes of a market, which has often been described as 'unrecognised' (Parker, 2003) and characterised by a 'shadow existence' (Steinhilper and Hudelmaier, 1993). Particularly the large number of independents in the automotive sector may often not be clearly identified as remanufacturers. In many cases, these businesses are very small and may name their activities 'refurbishing', 'refit' or 'repair'. The industry is too large to be completely overlooked by the public (Hormozi, 1999). Ayres and Ayres (1996) further endorse this view by arguing that remanufacturing has often been perceived as insignificant. However, it is expected that the sector will receive growing attention when the shortage of landfill sites induces governments to force manufacturers (OEMs) to take back used products (Ayres and Ayres, 1996).

3.3.2 Environmental Contribution

The largest coverage in the literature is made with regard to the remanufacturing sector's environmental performance. Lund (1996) explains that remanufacturing businesses contribute to the conservation of nature by saving valuable materials, energy, human effort, as well as capital equipment. Apart from claiming to be market leader in the 'exchange business' (VW, 2002), Volkswagen promotes the environmental-friendliness of their 'original exchange parts' (remanufactured replacement parts) on the company's website.

> *Through the remanufacturing of genuine exchange parts, 925,000,000 kilowatt hours of energy could be saved to date, which is sufficient to provide energy for the town of Kassel for a whole year. The steel which was obtained from the remanufacturing of 7,2 million engines, provides enough material to build the Eiffel Towers 47 times or the Golden Gate Bridge 155 times.*
>
> (VW, 2003b, translated from German)

A further, more detailed overview is given by Hormozi (1999), who portrays the energy savings generated by remanufacturing (Table 6). He also claims that the environmental benefits of remanufacturing equal the potential benefits of environmentally conscious manufacturing (Hormozi, 1999).

Metal	Energy requirements per 1 ton from primary ore (kWh/ton)	Energy requirements per 1 ton from scarp (kWh/ton)	Energy savings (kWh/ton)	Energy savings
Aluminium	51,379	2,000	49,379	96%
Copper	13,532	1,726	11,806	87%
Iron/Steel	6,481	1,784	4,697	74%
Lead	7,910	3,176	4,734	60%
Zinc	19,044	7,031	12,013	63%

Table 6: Energy Savings from Remanufacturing
(Source: figures from Hormozi, 1999)

Steinhilper (1998) further outlines that compared to material recycling, which may in some cases need even more energy than processes starting from ore, remanufacturing conserves the energy which is embedded in the product. Moreover, he argues that a study conducted by his research group discovered significant material and energy savings within the remanufacturing of automotive alternators and starters. Just 9% of the energy was consumed by a starter being remanufactured compared to a 100% in a new product. Material use amounted to 11% of the new product. Although various contributors have shown that remanufacturing may make a contribution towards environmental protection, the discussion within practitioner circles suggests that the environmental lobby does not have a positive attitude towards automotive remanufacturing.

> *With the introduction of the 'end of life vehicle directive' to be implemented in 2008 demanding that a vehicle manufacturer will recycle every vehicle they produce at the end of the useful life of that vehicle, will rebuilding be looked on more favourably by the environmental lobby? Perhaps incentives such as cash backs from the government to the rebuilding industry to recycle more products instead of importing new products will help.*
>
> (Vehicle Electrics and Electronics, 2003, p.37)

The above discussion indicates that the environmental contribution to sustainability with regard to energy, material and waste savings has been demonstrated by several contributors. For some it seems very obvious that recycling, re-use and remanufacturing have positive impacts for the environment. However, detailed analyses still need to be developed, also with regard to the automotive remanufacturing sector. This could be undertaken by establishing an eco-balance sheet for particular components. Lund (1996) confirms that the real extent of resource conservation still has to be investigated. The above points with regard to the contribution to the environmental, economic and social side of sustainable development are summarised in Table 7.

Sustainable Dimension	Contribution by Remanufacturing
Environmental	▪ Saving materials ▪ Saving energy ▪ Reduction of solid waste
Economic	▪ Generating tax power ▪ Saving capital equipment ▪ Reduction of waste processing costs
Social	▪ Employment ▪ Reduced costs of durable products ▪ Conservation of Labour ▪ Localisation of Economic Activity

Table 7: Remanufacturing: Contribution towards Sustainability

3.4 Internal and External Pressures on the Automotive Industry

In 2003, Murphy and Poist have undertaken a study which focused on the views and practices of US and non-US companies, regarding the management of environmental issues in logistics. They discovered that US and non-US (Canadian and West European) companies tend to apply green approaches to logistics mainly on the basis of two reasons. The first reason for adopting environmental policies was the compliance with governmental regulations and legislation. The second reason was the 'control of environmental costs'. Moreover, Murphy and Poist (2003) found that the views of US

companies on the major reasons for establishing these policies did not differ from views of non-US companies (see Table 8).

In the following sections, the main motives inducing environmental corporate behaviour are discussed. One of these motives, the ethical or moral responsibility has been previously presented. The following sections, however, elaborate on governmental regulations and economic factors. Although the literature consulted in this chapter is taken from the whole field of the environmental social sciences, the motives which were identified could also be found in the more specific literature on reverse logistics and product recovery (see Appendix D).

Reason	US Participants	Non-US Participants
Compliance with government regulations	84	95
Control environmental costs	70	76
Societal expectations	66	65
Minimise liability	63	49
Profit opportunities	22	35
Keep up with competitors	15	20

Table 8: Major Reasons for Adopting Environmental Policies (percentage indicating 'yes') (Source: Murphy and Poist, 2003)

3.4.1 Environmental Legislation

Since the reliance on voluntary action and self-regulation is not generally effective in ensuring that companies improve their environmental performance (Deutz, no date given), many researchers in the area of environmental business management, such as Handfield *et al.* (1997), Murphy and Poist (2003) and Toffel (2003) claim that legislation is one of the major causes for businesses to establish environmental strategies. Fleischmann *et al.* (2000) confirm that "legislation may impose producer responsibility, thus making recycling mandatory" (p.661). Some contributors therefore identify legislation as a major driving force for product recovery in general (e.g. Feldman *et al.*, 1999; Linton, J.D, 2000; Guide, 2000), and reverse logistics in particular (e.g. Beamon, 1999; Nagel and Meyer, 1999; Cairncross, 1992; Linton, J, 1999). Within

the European Community, the protection and preservation of the environment as well as its qualitative improvement is a major aim (CEC, 2002b).[12]

However, the Treaty not just incorporates European environmental matters, but takes an international view. Article 174 I demands for policies contributing to the resolution of regional and global environmental problems (CEC, 2002b). As will be shown later in this section, these principles can be found in many regulations within the European environmental policy. The Treaty therefore sets a framework for environmental regulations in the European Union. Two legal texts are of major significance for this research: the Directive on End-of-Life Vehicles (CEC, 2000) and the Directive on Waste and Electronic Equipment (CEC, 2001a, 2002c). In its preamble, the ELV Directive explains that the large amount of up to 9 million tonnes of waste caused in the Community by ELVs each year has to be dealt with. As a result, the ELV Directive was created. Approximately 14 million End of Life Vehicles (ELV) arise in Europe each year; 40 million world-wide (Ambrose, 2000).

The ELV Directive requires that car producers are responsible for the costs of recycling of vehicles put on the market after 1 July 2002. From 1 January 2007 they will be liable for recycling all vehicles, without consideration of a vehicle's age. The ELV Directive sets successive recycling requirements. By 1 January, 2006, all ELVs must have 85% of their materials re-used and recovered. By 1 January, 2015, these percentage targets will increase to 95% and 85%, respectively. However, the ELV Directive not only aims to improve the recovery of end-of-life vehicles, but also seeks to implement strategies which prevent the generation of waste by making producers responsible for the costs of the implementation (CEC, 2000). Steffen Aumann, person in charge for the BMW 3 Series' with regard to 'design for recycling', explains that not the older car generations are an issue, since their metallic content is recyclable and valuable. On the other hand, the increasing amount of plastics in more recent car models is a major obstacle to meeting the ELV regulation. Luxurious cars, such as the BMW 7 Series, are less likely

[12] Article 174 of the Treaty demands a 'prudent and rational utilisation of natural resources', hence there is the request for a cautious use of materials and the prevention of waste (Schäfer, 2000).

to be returned as 'natural ELVs'[13], however if they are, the additional comfort features (e.g. sound insulation) make recycling more difficult than the recycling of volume cars (Aumann, 2003). However, Aumann assumes that the main financial impact of ELVs will affect volume producers of middle-class cars.

Likewise, the WEEE Directive aims to provide an incentive for manufacturers to design electronic products, such as household appliances, more environmentally friendly. Moreover, the directive requires the establishment of recycling and re-use infrastructures. In order to achieve the sustainable economy, the directives apply the 'polluter pays principle', which means that vehicle manufacturers, as well as producers of electronic products are made responsible for the waste their goods represent after use.[14]

According to Van Hoek (1999), who extends the framework proposed by Kopicki *et al.* (1993), there are three approaches of how companies practice environmental management. The first approach is termed 'reactive approach' and characterises companies, which only undertake minimal changes to their activities, just enough to comply with environmental legislation. Hence, the organisation of such changes seems to be rather ad hoc than systematic. The second approach, the proactive approach, goes a step further by anticipating new environmental regulations. However, only the value-seeking approach demonstrates that environmental activities are a part of the corporate strategy, because of the commitment to integrate environmentalism into strategy. This level can only be achieved by taking a holistic environmental view which includes all members of the supply chain, such as suppliers, customers and end-users (Van Hoek, 1999).

[13] There are natural and premature ELVs. The main distinction between these is the fact that premature ELVs generally have a residual (positive) value, whereas natural ELVs tend to have a negative value. According to the Department of Trade and Industry (2002), premature ELVs often comprise accident write-offs and natural ELVs are cars which have reached the end of life naturally.

[14] The idea behind the polluter pays principle is the transfer of the waste responsibility from the user to the producer. "When the responsibility of end-of-life take-back is transferred to the producer, the producer will most likely minimize the end-of-life impact of the product" (Linton, J.D, 2000, p.32).

Handfield *et al.* (1997) distinguish six different modes of response to environmental issues: resistant adoptation, embracing without innovating, reactive, receptive, constructive and proactive. A company's response to environmental issues may therefore range from a minimal compliance with regulation (resistant adoptation) to an active inclusion of all participants (e.g. stakeholders) in the organisation's vision of short- and long-term environmental responsibilities (proactive) (Handfield *et al.*, 1997).

With a stronger focus on the take-back of end-of-life products, Toffel (2003) introduces six strategies which manufacturers pursue with regard to product take-back. This classification is practically oriented and investigates the extent to which a company co-operates with others. The degree of involvement may comprise long-term contracts with third party providers (recycling), joint ventures with recyclers or even the joint venture with a competitor in order to recover the end-of-life goods. Not least therefore, Bansal and Roth (2000) argue that it is fundamental to understand motives and strategies for corporate ecological responsiveness. In their eyes, it helps to predict ecologically based behaviour. If companies just comply with governmental regulations, they will consequently engage in the postulated activities, not in any others (Bansal and Roth, 2000).

This section has shown that environmental legislation may steer the extent to which companies engage in sustainable actions. Legislation may therefore be a tool for enhancing environmental friendly actions by corporations.

Is automotive remanufacturing induced by product take-back and recovery legislation, such as the European ELV Directive? (Research Question 4)

3.4.2 Economic Factors

Environmental legislation may just be one motive for corporations to engage in sustainable actions. Coming from a pure economic point of view, Wöhe and Döring (1996) explain that businesses, in the long-term, aim for profit maximisation. This also

signifies that businesses only sustain if they generate profits, or at least, cover all their costs. Hence, there is the assumption that 'corporate greening' has to be profitable – at least in the long run. Luthans *et al.* (1980) distinguish three phases of social responsibility. The first, the historic phase, aimed at profit maximisation and the belief that the business manager's only constraint is the legal framework to achieve this goal. Adam Smith encouraged the idea that each manager is acting in his selfish interest to promote the public good – guided by an 'invisible hand' (Smith, A, 1950). The regulation of the competitive marketplace as well as the drive for profit maximisation may result in the greatest wealth for a nation, hence the 'maximum public good' (Luthans *et al.*, 1980). This view was acceptable as long as the society perceived economic scarcity and the accumulation of wealth was a primary national goal. The exploitation of natural resources, employees (e.g. child labour) or unsafe working conditions were tolerated. However, with the dispersion of stock ownership of American corporations, the manager was seen as representative for a multitude of owners and contributor groups. Moreover, society developed into a pluralistic form, characterised by semi-autonomous and autonomous groups (Luthans *et al.*, 1980). Societal power was dispersed, too. This dispersion of power and influence nowadays comprises a variety of interest groups, such as environmental, consumer or industry associations. The changes in business ownership and society have led to the second phase, 'trusteeship management', as termed by Luthans *et al.* (1980). However, the maximisation of the 'public good' came even more into question when economic and materialistic scarcity vanished, with the result that the term of 'maximum public good' had to be redefined. The creation of the 'affluent society' (Galbraith 1987), has also shifted the goals in society and industry. Instead of struggling with fundamental problems (e.g. food scarcity), the societies in industrial nations are battling against direct and indirect results of their economic success, such as air pollution or degradation of the landscape (Luthans *et al.*, 1980). These issues seem to ask for new national and societal priorities.

The question arises to which extent industry adapts and complies with these new priorities. Still, there are certain (economic) expectations corporations have to fulfil. However, this section merely focuses on the (potential) profitability of product take-back and recovery, since it is relevant to the research.

Economic motives of product take-back and recovery are described as 'economic opportunity' by Bansal and Roth (2000). They explain that product recovery operations not only decrease costs because less materials or components have to be purchased, but nowadays, waste disposal costs play a major role in a manufacturing environment. Lynn Scarlett argues that "the competitive dynamic of the market place has always driven smart managers to search for ways to achieve energy efficiencies and dematerialize their industrial processes and products, because all this rebounds to the bottom line" (Lynn Scarlett in Anonymous, 2001, p.23). Particularly in countries with a stringent environmental legislation or land scarcity, manufacturers are facing high costs for landfill, particularly for hazardous waste. Ayres *et al.* (1997) furthermore state that for laser printers, for instance, disposal costs represent up to two percent of direct production costs. For cars this percentage may increase to three percent. Recycling or remanufacturing operations therefore reduce virgin material input, but also decrease disposal costs, since less scrap accumulates. Moreover, waste may be seen as a resource (Lamming and Hampson, 1996). Ayres and Ayres (1996) describe this phenomenon as 'the economics of win-win', which is a situation where waste is turned into a useful product. There are several examples of how the multiple benefits could be achieved through product take-back and recovery, such as copying machine remanufacturing at Xerox (Nagler, 1999) or power-tool remanufacturing at Robert Bosch (Klausner and Hendrickson, 2000).

Burke and Logsdon (1996) further add that corporate social responsibility may create short-term costs, but will pay off for the organisation in the long run. However, any rational company will only engage in profitable activities, which are those that create and increase shareholder wealth (Guide and Van Wassenhove, 2001). According to these authors, there seems to be the need for further research in this direction. "Despite the potential profitability of reuse and legislative requirements, there are no integrated decision frameworks to advice decision-makers about the economic viability of various reuse options" (Guide and Van Wassenhove, 2001, p.143). Hence, there may be examples of companies, which have introduced environmentally friendly measures with financial benefits. However, there seems to be an ongoing discussion about the profitability of product take-back and recovery, and in many cases, recovery is still more costly than disposal. The report by the Green Alliance gives insights into how

California, Denmark, Flanders, Massachusetts, The Netherlands, Sweden and Switzerland manage their (solid) waste strategies. Interviewees stated that the recycling of waste in California is probably more expensive than landfill in direct costs, but with regard to employment, it is seen as an overall benefit. "Recycling creates more jobs per tonne than disposal. It has created lots of jobs in collection and processing. These are good as first jobs and to get people into employment, but there are also some desirable white collar and driving jobs" (Kevin McCarthy in Green Alliance, 2002, p.2.3).

One major issue in making social responsibility profitable seems to be the lack of the incorporation of 'externalities' (e.g. pollution) into business accounting systems. (Smith, W.G.B., 1999-2001) claims that the main reason for sustainable production not to work, also in financial terms, is the 'underpricing' of natural resources. Hence, there are no incentives for businesses to cut back their use of these. Smith, W.G.B. (1999-2001) furthermore explains that the underpricing of resources has led to a prodigal behaviour regarding industrial management in the past. Corporations perceived that there were unlimited resources and unlimited amounts of waste could be produced, a phenomenon which Smith, W.G.B. (1999-2001) labelled 'once-through model of industrial production'. According to Todd (1994), there is the need for an all-inclusive environmental accounting system, which internalises environmental costs. In other words, (monetary) values have to be attached to environmental costs.

According to Ayres and Ayres (1996), economists assume that it is rather unlikely to achieve a 'win-win' situation, due to pure mathematical reasons.[15] Elkington (1994), on the other hand, speaks about a situation where three different parties could benefit from dealing carefully with natural resources: the corporations, the customer and the environment.

Hence, companies may pursue 'triple bottom line' strategies, which increase profits, reduce environmental impacts, and meet social commitments (Elkington, 1997). In his eyes, companies have no choice with regard to environmental regulations, however, he

[15] A more detailed discussion on the economic explanation of the 'optimal abatement in economic equilibrium' can be found in Ayres and Ayres (1996), pages 22-25.

believes in a competitive advantage that may develop from a close co-operation between companies, their suppliers, customers and other stakeholders (including competitors). One of the main obstacles of generating profits through recycling, remanufacturing or re-using products and materials has been identified by Biddle (1993). In his point of view, the major link to successful recovery operations is the willingness of customers to buy recovered products, or, as Biddle (1993) termed this the difficulty of 'building demand'. However, competition in the market for recovered materials is intense. Furthermore, there is a variety of attractive substitutes, which makes recycling unprofitable. "The market is so flooded with 'clean' material that the price for recovered forms of this plastic from curbside recycling programs has plummeted. Recycled commodities often end up competing against one another as well" (Biddle, 1993, p.146). He hereby raises an important issue. Chapter Five will outline that within the market for automotive replacement parts, remanufactured products compete with a number of other products, including new products of different qualities. For a general customer, this may be a choice between 'new' and, in his eyes, 'used'. The myth of recovered products being qualitatively inferior to new products is an aspect, which Biddle (1993) describes as a key issue within the management and distribution of recycled products.

There have been attempts to examine the correlation between corporate environmentalism and profitability. Klausner and Hendrickson (2000), for example, distinguish between recycling, which they believe to be unprofitable, and remanufacturing, which seems to be profitable. Walley and Whitehead (1994), however, state that mutually profitable situations are unrealistic: "responding to environmental challenges has always been a costly and complicated proposition for managers. In fact, environmental costs at most companies are skyrocketing, with little economic payback in sight" (p.46). The authors even claim that those benefits should not be the foundation of a company's environmental strategy, since "ambitious environmental goals have real economic costs" (Walley and Whitehead, 1994, p.46). However, managers expect returns from any business, and thus may not adopt green approaches if returns are not anticipated. A CEO of a large European automotive company once stated, "Why should I make an effort to invest in greening if it does not generate any revenues?" (quote in Van Hoek, 2002, p.143). Therefore, Schendler (2002) concludes that "corporate sustainability won't occur without a company mandate that springs from ethics, not

economics" (p.29). Hence, this argument refers to what has been discussed within the section on corporate social responsibility. Morality and ethics outplay economics as reasons for corporate sustainability.

With regard to remanufacturing, however, it seems as though recovery operations are more likely to generate profits, since it not just recovers the material, but also the labour and value added incorporated into the product (Seitz and Wells, 2003). Strandberg (1990), for example, speaks about the remanufacturing of whole busses and trains, which is significantly cheaper than the purchase of a new product. Steinhilper (1998) and Amezquita *et al.* (1995) have also pointed out customer benefits through major price differences between new and remanufactured products. This is particularly attractive if remanufactured products are given the same warranties as new products (Amezquita *et al.*, 1995).

Following this discussion, this dissertation seeks to examine the role of a direct economic motive with regard to automotive remanufacturing.

Is automotive remanufacturing induced by direct economic motives (i.e. profitability of remanufacturing)? (Research Question 5)

With regard to this research question, the author distinguishes between a 'direct economic motive' and the contribution to group-wide profitability that remanufacturing may make. The *direct economic motive* is therefore understood as the profitability that directly results from the sale of remanufactured products. In other words, the direct economic motive refers to the (positive) result that is left after all costs (for example costs for product take-back, recovery, distribution and marketing) have been deducted from the sales price. Due to confidentiality or limited access to relevant data, a profitability analysis may not be possible. However, this research investigates the role of a direct economic motive with regard to the establishment and undertaking of automotive remanufacturing from and OEM perspective.

On the other hand, remanufacturing may also contribute to group-wide profitability. It may therefore play a part with regard to the development of a group-wide competitive advantage as defined by Porter (1985). Porter's model of the value chain (Porter, 1985; p. 37) comprises a series of primary activities (inbound logistics, operations, outbound

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logistics, marketing and sales, services) and several support activities (firm infrastructure, human resource management, technology development, procurement) that create value. It may therefore be likely that, as opposed to a direct economic motive, there may be an indirect effect of automotive remanufacturing, resulting in a group-wide competitive advantage. It is very challenging to identify such impact of remanufacturing as it may not be directly linked with the operation. A good case in point are different aspects of customer loyalty, such as the serviceability of cars, of which one component is the supply of remanufactured aggregates. However, as this is a very complex and non-transparent issue, this thesis solely focuses on the 'direct economic motive' as reason for automotive remanufacturing.

3.5 Conclusion

This chapter has emphasised the importance of a thorough theoretical grounding for any research. It has also raised the issue of the lack of a theory for closed-loop supply chain management. This thesis therefore aims to make a theoretical contribution to closed-loop supply chain management. Based on empirical research (Chapters Six, Seven and Eight), new elements for this theory will be developed in Chapters Nine and Ten and summarised in Chapter Eleven. The discussion on the lack of a theoretical framework for research in closed-loop supply chain management builds the basis for the selection of appropriate research tools and techniques in the following Chapter Four.

Moreover, it was shown how the current automotive industry responds to external pressures in order to engage in corporate environmentalism. Three specific pressures or motives for corporate greening were identified from the literature: the 'ethical', the 'legal' and the 'economic' motive. As a result, three further research questions were developed. These research questions aim to examine, to which extent those motives are relevant within the automotive remanufacturing sector. The following chapter on research methods will further extend this foundation for the research which was created within the Chapters Two and Three. Chapter Four will select and evaluate the appropriate research methods and tools for answering the five research questions.

Chapter Four
Methodological Considerations

4.1 Introduction

In the previous chapters, existing research was reviewed and discussed and five research questions were developed. Chapter Four therefore presents the essential link between research problem (research questions) and the empirical research.

Firstly, this chapter reviews the appropriate methodology which will be applied to this research. It outlines the merits and weaknesses of the methodological considerations in general. Thereafter, it applies these considerations onto this research and justifies why the selected research strategy and data collection methods have been perceived as the most suitable for this research.

Secondly, the chapter presents the overall line of enquiry and how it has developed in the course of the research. The research has initially started broad and has gradually narrowed down over time. In addition, the approaches of 'grounded theory' and 'exploratory research' have demanded changes to the direction of the research. Chapter Four presents and explains why and how these changes have occurred and how they are justified. The chapter concludes with a discussion on the overall validity of the research methodology that was adopted within this research.

4.1.1 Approaches to Theory-Building

According to Trochim (2002c), theories can be developed through an inductive research approach. Inductive thinking is hereby defined as research that begins with a specific observation and moves towards broader generalisations and theories. Stuart *et al.* (2002) confirm that the early stages of theory development are usually observation based and include inductive models. The opposite approach, which is characterised by working from the general to the more specific, is defined as deductive thinking (Trochim, 2002a).

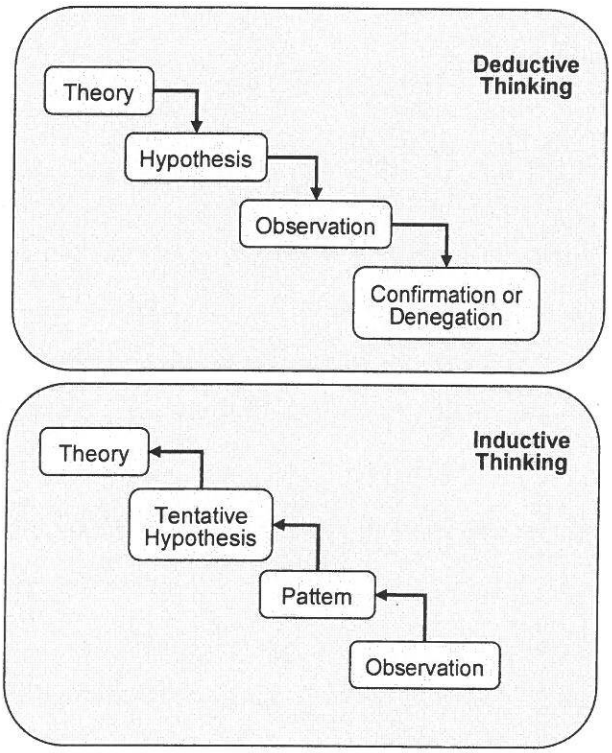


Figure 8: Inductive and Deductive Thinking
(Source reproduced from Trochim, 2002a)

The immaturity of the field of closed-loop supply chain management, which has been outlined in Chapter Two, asks for an inductive approach to research. Within social science research, this approach has often been defined as 'grounded theory' (Glaser and Strauss, 1967). As the term indicates, the theory is grounded in the data. However, there is a second element to grounded theory, in the form of a continuous analysis and re-

evaluation of the data while the research is undertaken. Glaser and Strauss (1967) further add that the aim is to discover theory, rather than to verify it.

> *Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analyzed. Theory evolves during actual research, and it does this through continuous interplay between analysis and data collection.*
>
> (Strauss and Corbin, 1994, p.273)

According to Robson (2002), grounded theory is both, a research strategy and a tool to analyse data. Due to the research needs outlined in the previous chapters of this thesis, an inductive approach was applied to this research. Wacker (1998) explains that theory can be developed from analytical or empirical research. The key difference between these approaches is that analytical research often uses logical, mathematical or statistical methods, in order to provide new insights into traditional problems. Empirical research, on the other hand, uses primary data to form the theory and may therefore apply 'real-world' research strategies, such as case studies (Wacker, 1998). The need for more empirical research in the area of closed-loop supply chain management has been extensively outlined in Chapter Two. Handfield and Melnyk (1998) present five stages of theory-building: discovery and description, mapping, relationship building, theory validation and theory extension or refinement. They furthermore outline the appropriate research methods for each step. In their eyes, quantitative methods, such as experiments or surveys, are merely appropriate in the last two phases of theory-building (as shown in Table 9). It is therefore questionable, why previous research in the area of closed-loop supply chain management has excessively utilised quantitative approaches, which seem to be more appropriate for theory validation, testing, extension or refinement, rather than focusing on the discovery of an overall closed-loop supply chain management theory. Consequently, this research seeks to fill a gap by aiming to discover a theory for closed-loop supply chain management as a whole as opposed to establishing a theoretical basis for specific elements (e.g. inventory control) of the closed-loop supply chain. This is contradictory to what previous research has investigated, in which an often narrow perspective on individual aspects of the closed-loop supply chain (e.g. disassembly, product recovery or inventory management) was taken.

Handfield and Melnyk (1998) clearly point out that the first three steps to theory-building comprise qualitative strategies and methods, such as in-depth case studies, unfocused longitudinal field studies and multi-site case studies. Table 9 displays the tools, techniques and methods applied within theory-building processes. It demonstrates which strategies are most likely to achieve the desired results in which stage of the theory-building process. With regard to Table 9, the first three steps of the strategies for theory-building are applied within this research. As it will be further outlined in this chapter, the first two steps are applied by the case studies. Hereby, key variables, patterns and themes are discovered, which constitute the *'what'* element of a theory (as defined by Whetten, 1989). Step three in Table 9 aims to discover the links and relationships between variables, or the *'how'* and *'why'* elements of an initial, rudimentary theory. In this thesis, this will be achieved by subsequent case study research, but also by the testing and verification of the case study findings in the questionnaire survey. Chapter Eleven will summarise the contributions to a theory for closed-loop supply chain management.

Purpose	Research Questions	Structure of Research	Data Collection Methods	Data Analysis
1a) Discovery => uncover areas 1b) Description => explore territory	▪ What is going on? ▪ Does this justify research? ▪ What is there? ▪ What are the key issues? ▪ What is happening?	▪ In-depth ▪ Unfocused ▪ Longitudinal studies ▪ Case studies	▪ Observation ▪ Interviews ▪ Documents	▪ Insight categorization ▪ Expert opinion ▪ Descriptions ▪ Content analysis
2) Mapping => identify variables => identify territory	▪ What are the key variables? ▪ Identification of *'what'* ▪ What are the critical themes, patterns and categories?	▪ In-depth ▪ Focused case studies ▪ Multiple case studies ▪ Best practice case studies	▪ Observation ▪ In-depth interviews ▪ Diaries ▪ Survey questionnaires	▪ Verbal protocol ▪ Content analysis ▪ Cognitive mapping
3) Relationship-building => improve map of territory => identify relationships between variables	▪ What are the patterns of links between variables? ▪ Identification of *'how'* ▪ Identification of *'why'* ▪ Can a pattern in the relationships be identified? ▪ Why should relationships exist?	▪ In-depth ▪ Focused case studies ▪ Multiple case studies ▪ Best practice case studies	▪ Observation ▪ In-depth interviews ▪ Diaries ▪ Survey questionnaires	▪ Verbal protocol ▪ Content analysis ▪ Cognitive mapping ▪ Factor analysis ▪ Correlation analysis
4) Theory validation => test theories => predict future outcomes	▪ Are the theories able to survive the test of empirical data? ▪ Is there a causal relationship between theory and behaviour?	▪ Experiment ▪ Quasi-experiment ▪ Large-scale sampling of population	▪ Structured interviews ▪ Documents ▪ Open and closed-ended questionnaires ▪ Surveys	▪ Triangulation ▪ Analysis of variance ▪ Regression ▪ Path analysis
5) Theory extension and refinement => expansion of theoretical map => structuring theory	▪ How generalisable are the theories? ▪ Where does the theory apply? ▪ Where don't the theories apply?	▪ Experiment ▪ Quasi-experiment ▪ Large-scale sampling of population	▪ Structured interviews ▪ Documents ▪ Open and closed-ended questionnaires ▪ Surveys	▪ Triangulation ▪ Analysis of variance ▪ Regression ▪ Path analysis

Table 9: Matching Research Strategy with Theory-Building

(Source: summarised from Whetten, 1989, and Handfield and Melnyk, 1998)

4.1.2 Relationship between Paradigm, Methodology and Methods

According to Hussey and Hussey (1997), a paradigm indicates the researcher's philosophical assumptions and positioning and the way of 'how research should be conducted'. Guba and Lincoln (1994) furthermore add, that a paradigm is "[...] the basic belief system or worldview that guides the investigator, not only in choices of method but in ontologically and epistemologically fundamental ways" (p.105). However, the term paradigm is used loosely in academic research (Guba, 1990). Kuhn (1962), for example, used the paradigm concept in 21 different ways. He thereby provoked a problem of interpretation, as well as a problem of the use of the term 'paradigm' in social science research (Masterman, 1970). Guba (1990) explains that the non-existence of a clear definition of the term paradigm is an advantage to every researcher and reader, who can refine the definition as appropriate. In a generic sense, he therefore sees a paradigm as a basic set of beliefs, which direct and influence action in research, for example positivism, post positivism or constructivism. In this dissertation, the term paradigm is likewise seen as a philosophical reflection on basic beliefs about the researcher's world, as also pointed out by Morgan (1979).

Depending on the area of research, major contributions on research methodology consider different research paradigms. In social science research, a widespread classification differentiates between positivism, post positivism, critical theory and constructivism (Guba and Lincoln, 1994). Other social scientists, as for example, Bailey (1994) and Hammersley and Atkinson (1995) identify ethnography, ethnomethodology or 'scientific' (statistical) paradigms as common social research paradigms. An even broader spectrum of paradigms is given by Morgan and Smircich (1980).

On the other hand, in business and management research, as opposed to social science research, some contributors keep the philosophical positioning simplified. A very basic approach, for instance, is taken by Hussey and Hussey (1997), who distinguish between a positivist and a phenomenological paradigm. This simplified route is also taken by Easterby-Smith *et al.* (1991), who refer to positivism and phenomenology as the 'two main traditions'. Hussey and Hussey (1997) explain that a positivist paradigm can also

be described as quantitative, objectivist, scientific, experimentalist or traditionalist paradigm. Qualitative, subjective, humanistic and interpretivist, on the other hand, are terms often used to define the phenomenological paradigm. Easterby-Smith *et al.* (1991) give an overview of these characteristics.

	Positivist Paradigm	Phenomenological Paradigm
Basic beliefs:	▪ The world is external and objective ▪ Observer is independent ▪ Science is value-free	▪ The world is socially constructed and subjective ▪ Observer is part of what observed ▪ Science is driven by human interests
Researcher should:	▪ Focus on facts ▪ Look for causality and fundamental laws ▪ Reduce phenomena to simplest elements ▪ Formulate hypotheses and then test them	▪ Focus on meanings ▪ Try to understand what is happening ▪ Look at the totality of each situation ▪ Develop ideas through induction from data
Preferred methods include:	▪ Operationalisation of concepts so that they can be measured ▪ Taking large samples	▪ Using multiple methods to establish different views of phenomena ▪ Small samples investigated in depth or over time

Table 10: Key Features of the Positivist and Phenomenological Paradigms (Source: taken from Easterby-Smith *et al.*,1991, p.27)

However defined, Guba and Lincoln (1994) argue that every paradigm encompasses three elements: ontology, epistemology and methodology. According to how proponents respond to these three characteristics, their paradigmatic position can be identified (Guba, 1990). Appendix E further explains the ontological, epistemological and methodological concepts for four different paradigms.

- **Ontology**: Indicates the form and nature of reality, for example if a 'real' world is assumed. In other words, ontology represents "the branch of philosophy concerned with the study of the nature of the being" (Wolman, 1973, p.262). Guba (1990) further adds that ontology also explains the nature of the 'knowable' and the 'reality'.

- **Epistemology**: Indicates the relationship between the 'knowing' person and the researcher (enquirer) and tries to characterise knowledge, for example if subjective truths count as knowledge. More simply, Hussey and Hussey (1997) explain that epistemology provides information on the relationship between the researcher and the researched.
- **Methodology**: Indicates how the researcher gains the knowledge about the world (process of the research). However, the question of methodology cannot be reduced to a question of methods. Hence, methodology is the combination of techniques applied to the research, whereas methods represent the individual techniques for data collection or analysis (Easterby-Smith *et al.*, 2002).

Based on the decisions made in the previous sections in the form of theory-building through an empirical and real-world study of the phenomena, this research takes a phenomenological perspective. In the sections following later in this chapter, the author explains how the characteristics of the phenomenological approach have affected the research.

This section now further explains how research paradigm and methodology are related. As previously noted, Easterby-Smith *et al.* (2002) outline that 'methodology' is the overall term for a variety of techniques used to enquire about a specific situation, whereas methods represent individual techniques (tools) for data collection or data analysis. A rich variety of qualitative (phenomenological) and quantitative (positivistic) methods are used in research. "However, a method is not necessarily phenomenological or positivistic by its label, but by how it is used" (Hussey and Hussey 1997, p.140).

Morgan and Smircich (1980) argue that there is a link between paradigm and method. Hereby, qualitative and quantitative distinctions stand for different epistemological viewpoints rather than being different data collection techniques.

> *...choice and adequacy of a method embodies a variety of assumptions regarding the nature of knowledge and the methods through which that knowledge can be obtained, as well as a set of root assumptions about the nature of the phenomena to be investigated.*
>
> (Morgan and Smircich, 1980, p.491)

This argument is backed up by Burrell and Morgan (1979), who claim that four paradigms exist in organisational research, the functionalist, the interpretive, the radical humanist and the radical structuralist paradigm. The main paradigms are the functionalist and the interpretive paradigm, which the authors see corresponding to quantitative and qualitative methods. According to the authors, the functionalist paradigm is influenced by a positivist approach and methods like surveys and questionnaires are used within functionalist research. On the other hand, interpretive research focuses on the perspective of participants and ethnographic methods are applied. Furthermore, Burrell and Morgan (1979) see an incompatibility of the two approaches, as each paradigm perceives the world from a different perspective. However, the adoption of Morgan and Smircich's (1980) as well as Burrell and Morgan's (1979) viewpoints, and therefore the declaration of quantitative and qualitative research as competing approaches, would have destructive impacts on any research. Their perspectives eliminate the benefits of methodological triangulation. Hence, in this research, the opposite point of view, as proposed by Guba and Lincoln (1994), is adopted. As a result, "[...] both qualitative and quantitative methods may be used appropriately with any research paradigm" (Guba and Lincoln, 1994, p.105). Bryman (1989) also denies a relationship between the research paradigm and data collection methods by arguing that each method should be appreciated as a means of data collection.

> *...each design and method should be taken on its merits as a means of facilitating (or obscuring) the understanding of particular research problems, and that a fetishistic espousal of favoured designs or methods and an excessive preoccupation with their epistemological underpinnings can only stand in the way of developing such an understanding.*
>
> (Bryman, 1989, p. 255)

Historically, research in supply chain and operations management has been based on the positivist paradigm with the application of quantitative modelling and statistical analysis. However, the field has further developed when contributors began to document the importance and rigor of case and field research. With regard to logistics management, for example, Halldórsson and Aastrup (2003) recognise a trend in the logistics discipline with a methodological shift from a traditional positivist paradigm

towards a multi-paradigmatic approach. Some contributors even claim that the application of qualitative methods and a multi-method approach are preferable for theory-building.

> *...the objectivity provided by quantification in the rationalist methods can be a hindrance in the attempt to build theory because a qualitative understanding of the quantified factors is still required for theories to be accepted by others in, and outside, the field. But a major conclusion here is that these alternate research methods are not mutually exclusive and, if combined, can offer even greater potential for enhancing new theories than either method alone.*
>
> (Meredith, 1998, p.442)

4.2 Selection of Appropriate Research Strategy and Methods

In this section, the selected research strategy and data collection methods are presented. Their selection was influenced by the research needs and the research problem, as outlined d in Chapters Two and Three. Table 11 summarises the research questions, the chapters in which they have been identified, as well as the chapters in which the results are presented and the findings discussed.

<table>
<tr><th>Research Question</th><th>Identification</th><th>Presentation of Results</th><th>Discussion of Findings</th></tr>
<tr><td>1. Which existing closed-loop supply chain structures and models are relevant to the automotive industry?</td><td rowspan="2">Chapter 2</td><td rowspan="5">Chapter 6
Chapter 7
Chapter 8</td><td rowspan="2">Chapter 9</td></tr>
<tr><td>2. Which existing remanufacturing process structures are relevant to the automotive industry?</td></tr>
<tr><td>3. Is automotive remanufacturing induced by the corporation's needs to be morally or ethically responsible for its actions?</td><td rowspan="3">Chapter 3</td><td rowspan="3">Chapter 10</td></tr>
<tr><td>4. Is automotive remanufacturing induced by product take-back and recovery legislation, such as the European ELV Directive?</td></tr>
<tr><td>5. Is automotive remanufacturing induced by direct economic motives (i.e. profitability of remanufacturing)?</td></tr>
</table>

Table 11: Summary of Research Questions

Although the previous section has supported the argument of Bryman (1989), in which he claims that there is no relationship between research paradigm and data collection methods, the author assumes that there is an interrelation between the research questions and the data collection methods. With regard to qualitative research, Holliday, A. (2002) has highlighted that data collection methods should be consistent with the research questions. Moreover, they should be chosen in a way that these are most appropriate for solving the research questions. "It is therefore very clear that one does not *begin* by choosing a method. Methods can be sufficiently flexible to grow naturally from the research question, and in turn from the nature of the social setting in which the research is carried out" (Holliday, A, 2002, p.21).

4.2.1 The Case Study Strategy

Case study research strategies have traditionally been used in exploratory research (Yin, 1994). However, today, case studies are considered appropriate within most research designs. Therefore, exploratory, descriptive, but also explanatory case studies exist (Yin, 1981a, b). The unit of analysis (case) can be an organisation, a department or occurrence (Yin, 1994; Voss, 2002), but also social entities, such as social groups, communities or organisational events (Hakim, 1987). Conducting a case study involves the researcher to gather a considerable amount of data, so as to develop a clear picture of the phenomenon (McCutcheon and Meridith, 1993). Case studies are flexible and have been successfully applied in a variety of areas, such as education, food, health service, electrical engineering (Gowler et al., 1993) and in operations and supply chain management (Voss *et al.*, 2002). Yin (1981a, 1981b) claims that case studies are the most appropriate research strategy if there is the need to examine a phenomenon in its real-life context and if there is a lack of clarity regarding the boundaries between the particular phenomenon and its context. Within a case study strategy, researchers may select a variety of methods and tools for data collection. In other words, the strategy does not predetermine how data is collected. There may be single and multiple case studies. Yin (2003) presents examples in which a single case study is preferred to a multiple case approach, however, in most disciplines, the multiple case study design is perceived as more robust (Herriott and Firestone, 1983).

As a research strategy, case research is very flexible and most suitable for theory-building. Eisenhardt (1989), one of the main contributors in organisational case study research, argues that the development of theory is central to organisational research. Theories were formerly generated from literature, common sense and experience, but case study research has added another dimension to theory-building. Yin (1994) further adds that a well-structured case study in explanatory or exploratory research unravels a new part of theory through the examination of various arguments. Therefore, a case study strategy is appropriate for generating theories on new, organisational phenomena (Meredith, 1998). Moreover, various contributors claim that case study research supports concept testing and application. A concept can be described as "[...] a generalized idea about a class of objects, attributes, occurrences, or processes that has

been given a name" (Zikmund, 1994, p.20). Within the theory-developing process, the researcher describes phenomena, which are then categorised into concepts (Voss *et al.*, 2002). Voss *et al.* (2002) furthermore state that case study strategies are appropriate for testing and applying concepts before they develop into theories. Although a concept can be valid in a single case, it cannot be claimed to be generally applicable to an entire population.

4.2.2 General Criticism of Case Study Research

Main criticism of case study research concerns the lack of generalisability, replicability and validity (Yin, 1994). Mason (1996) describes these three aspects as different types of measurement for evaluating the quality and rigour of the research. Furthermore, Silverman (1985) expresses doubts regarding the case selection. This section will discuss weaknesses which may occur within case study research and demonstrates how these can be overcome.

Validity

Validity is concerned with the issue of research accuracy and the 'fit' of methodology and research questions. In other words, if the research is valid, "it means that you are observing, identifying, or 'measuring' what you say you are" (Mason, 2002, p.39). Easterby-Smith *et al.* (1991) refer to validity as the full access to knowledge and meanings, whereas Yin (2003) differentiates between three types of validity: internal, external and construct validity. For each of these, there are case study 'tactics', which ensure that the particular type of validity is addressed. According to Yin (2003), construct validity refers to the operational measures selected for the research. To ensure validity, these measures need to be able to measure exactly what the researcher has intended to measure. In other words, construct validity refers to the right selection of 'measuring tools'. With regard to case study research, construct validity may be guaranteed through obtaining data from multiple sources and by asking key informants to control case study reports (Yin, 2003). Patton (1987) confirm s that through the application of more that one data collection method, the so-called 'methodological triangulation', the validity of any research may be increased. With regard to

methodological triangulation, "[...] the potential problems of construct validity also can be addressed, because the multiple sources of evidence essentially provide multiple measures of the same phenomenon" (Yin, 1994, p.92).

Internal validity, on the other hand, is only critical for explanatory or causal case studies, but not for descriptive or exploratory case studies, as Yin (2003) points out. If the researcher concludes that there is a causal relationship between two variables and this relationship does not exist, internal validity is threatened (Yin, 2003). Since the research questions within this research do not investigate a causal relationship between two variables, internal validity does play a minor role with regard to causal relationships. However, the second concern with regard to internal validity refers to "the broader problem of making interferences" (Yin, 2003, p.36). This is particularly critical within case study research. Tables 12 and 32 demonstrate how internal validity was ensured within this research.

Generalisability

According to Meredith (1998) generalisability, or external validity, is problematic for case studies, since it is often assumed that research findings are only valid for the particular case in which the observations were made. In comparison to that, researchers applying algorithmic and simulation modelling claim that their results are largely generalisable, because they are applicable to any situation and timeframe (Meredith, 1998). However, some types of research do not even search for generalisable findings (Punch, 1998). As a result, this limitation has to be seen in perspective. Yin (2003) recommends a replication of findings in further cases in order to ensure external validity, which he termed 'replication logic'.

Replicability

Replicability, also often called reliability, is the demonstration of the fact that the operations of a particular research could be repeated and the same results would be found (Yin, 2003). Meredith (1998) therefore defines the replicability of a study as duplicating it, where the subsequent researcher 'should get precisely the same results'.

Replicability is a serious issue in case study research. Critics often argue that the same case conditions never occur, and therefore cases cannot be replicated (Hamel *et al.*, 1993). However, in order to generalise case study results, a certain degree of replicability is necessary.

Easterby-Smith et al. (1991) differentiate between positivist and phenomenological reliability. Positivist reliability is addressed, if the methods used by one researcher measure the same result on different occasions, whereas the phenomenological reliability questions if different researchers on different occasions will come to similar observations. Meredith (1998) furthermore stresses that replicability within case studies has to be conceived in a different way, given the fact that each case with its conditions is unique. This does not imply that a case study research design is not scientific. Replicability is acquired by applying the theory generated from a first case to a second case study. Yin (2003) highlights further guidelines for enhancing a case study's reliability, for example through the use of case study protocols or databases.

Case Selection

Silverman (1985) argues that within quantitative surveys, the researcher carefully selects the sample to ensure that bias is limited, whereas the case-selection in the case study design is highly biased.

> *...the analyst selects cases only because he believes they exhibit some general theoretical principle. His account's claim to validity depends entirely on demonstrating that the features he portrays in the case are representative not of a population but of this general principle.*
>
> (Silverman, 1985, p.113).

Eisenhardt (1989) , Lewis, M.W (1998) and Voss *et al.* (2002) therefore offer a range of selection and search strategies in order to limit bias. These strategies include literature reviews, bibliographies, case catalogues or case collections (Voss *et al.*, 2002). However, the case selection strongly depends on the research project. Eisenhardt (1989) explains that cases are often chosen to replicate previous cases or extend emergent theories. Miles and Huberman (1994) suggest choosing a typical, representative case or

cases with contrasting characteristics, so as to highlight the differences being studied. However, it has to be noted that within a doctoral dissertation, case selection is often pre-determined by constraints such as financial means or access to case companies.

Table 12 illustrates the critical points within a case study strategy and proposes countermeasures. Section 4.4.3 will further demonstrate how these issues have been addressed within this particular research.

Point of Criticism	Proposed Countermeasures
Validity	▪ Triangulation of methods and data (Patton, 1987; Denzin, 1998; Punch, 1998) ▪ Multiple case studies (Yin, 1994, 2003)
Generalisability	▪ Greater depth of observation; in-depth case studies (Meredith, 1998; Voss *et al.*, 2002) ▪ 'Replication logic' (Yin, 1994, 2003)
Replicability	▪ Applying ideas and concepts to more than one case (Meredith, 1998) ▪ Generating case study protocols and databases (Yin, 1994)
Case selection (bias)	▪ Search strategies as suggested by Lewis (1998) ▪ Choosing a typical, representative case (Miles and Huberman, 1994) ▪ Replication of previous cases (Eisenhardt, 1989)
Time-consuming and expensive	▪ Iterative triangulation through literature reviews, case evidence and intuition (Lewis, M.W, 1998)

Table 12: Case Study Weaknesses and Proposed Countermeasures

4.2.3 Data Collection through Interviewing

Interviews are seen as a positivist and phenomenological method for data collection (Hussey and Hussey, 1997). They are different in the way they are conducted. Unstructured questions are commonly used in ethnographic interviewing, whereas in using a positivist approach, questions are structured (Fetterman, 1998).

An interview is defined as a discussion with a purpose (Saunders, M.N *et al.*, 1997). Although the interview can be structured or semi-structured, it is invented anew every

time it is conducted. This fact is enhanced by changing interviewees, as well as modifications of place and time (Seidman, 1991; Fettermann, 1998; Atkinson *et al.*, 2001). Interviewing was the main data collection method within this research. Most of the interviews were conducted face-to-face. Others were conducted by telephone or electronic mail (as shown in Appendix F). In this research, interviews were conducted to obtain facts, figures and opinions. They were of a semi-structured nature and ranged from 30 minutes to several hours. In most of the cases, secondary or archival data, such as company reports or presentations, were obtained during the interview to support the argument.

Hammersley and Atkinson (1995) claim that interviewing is the most suitable method for collecting insights, which could not be obtained otherwise. They furthermore suggest a combination of interviewing and observation, since observation helps the interviewer to interpret of what has been said. Observation may therefore validate what has been discussed in the interviews. Structured interviews comprise a standardised set of questions, which aim at obtaining quantitative results from a selected sample. Semi- and unstructured interviews, on the other hand, are generally more flexible and may contain open-ended questions in which the interviewee may express specific viewpoints. Moreover, unstructured interviews leave room for the interviewer to probe or follow up individual aspects. Oppenheim (1992) provides a very detailed discussion on the advantages and disadvantages of standardised versus in-depth interviews.

However, Easterby-Smith *et al.* (2002) recommend the semi-structured interview for cases, where responses need to be explored and clarified, as within an exploratory research design. Burgess (1982) adds that the interview is "[...] the opportunity for the researcher to probe, deeply to uncover new clues, to open up new dimensions of a problem and to secure vivid, accurate, inclusive accounts from informants that are based on personal experience" (p.107).

Easterby-Smith *et al.* (2002) summarise that interviews are an appropriate research method, if the researcher needs to understand the construct of the respondent's environment in order to discover opinions and beliefs. Secondly, interviewing is a suitable method if the interviewer intends to develop an understanding of the

interviewee's world. The aim of exploratory interviews, which were conducted at various stages within this research, is clearly illustrated by Oppenheim (1992). The purpose of applying an exploratory nature to an interview is "[...] to develop ideas and research hypotheses rather than to gather facts and statistics. [The exploratory interview] is concerned with trying to understand how ordinary people think and feel about the topics of concern to the research" (Oppenheim, 1992, p.67). Table 13 summarises what has been explained in this section.

Method Interviewing	
Characteristics	Verbal interaction
Forms	▪ Structured ▪ Semi-structured ▪ Informal ▪ Retrospective
Merits	▪ Gathering opinions, facts and perceptions ▪ Flexible ▪ Possibility to grasp non-verbal cues
Weaknesses	▪ Unpredictable ▪ Involves interpretation ▪ Data accumulation

Table 13: Characteristics of Interviewing as Method for Data Collection

4.2.4 General Criticism of Interviewing

Zikmund (1994) illustrates that the so-called response bias may occur within the verbal interaction between interviewer and interviewee. Respondents may give untrue or modified answers, because they believe these are be tolerated by their superior, their colleagues or by society in general. Zikmund (1994) calls this to 'save face' in the presence of an interviewer. Responding in an 'accepted' way may also be caused by the interviewer's status. Interviewees may fear that the researcher forwards information to the superiors, for example.

Another limitation to interviewing is the occurrence of administrative errors. These administrative errors comprise data processing errors, sample selection errors,

interviewer errors or the interviewer cheating (if external researchers are employed to carry out the interviews). Zikmund (1994) asserts that these errors are all based on carelessness caused by confusion, neglect or omission. One countermeasure for eliminating interview bias is to consult further interviewees on the same questions or to verify the information by re-interviewing previous respondents. Sayer (1984) therefore supports the use of large-scale and formally standardised questionnaire and interview surveys, since these eliminate 'observer-induced bias', such as the administrative errors outlined above. Within these standardised interviews, each respondent is asked the same questions in a controlled setting. Ghauri *et al.* (1995) confirms that structured and semi-structured interviews are less vulnerable towards bias.

4.2.5 Data Collection by Questionnaire

A questionnaire comprises a list of carefully selected and formulated questions, which are piloted, reviewed and then applied to the sample population. Within quantitative research, questionnaires are generally used for large-scale mail surveys. Hussey and Hussey (1997) suggest that a positivist paradigm often implies closed questions, whereas open-ended or open questions are used within phenomenological research. In both cases, however, questionnaire data can be coded, computer processed, and analysed. One of the method's main requirements is to ensure that all respondents understand the questions in the same way and that, if the questionnaire is conducted face-to-face rather than self-administered, all interviewees are asked in the same way. Within the questionnaire design process, the construction of questions is often underestimated. However, Zikmund (1994) states that any survey or questionnaire is just as good as the questions, which are being asked. Researchers therefore have to analyse the relevancy and accuracy of each question. This includes issues, such as how questions should be phrased and in what sequence they should follow each other. The survey's characteristics, its merits and weaknesses, are illustrated in Table 14.

Method Questionnaire	
Characteristics	List of carefully structured questions
Forms	▪ Postal questionnaire ▪ Telephone ▪ Face-to-face ▪ Electronic mail
Merits	▪ Low cost of data collection ▪ Low cost of processing ▪ Avoidance of interviewer bias
Weaknesses	▪ Generally low response rate ▪ Consequent biases possible ▪ No opportunity to correct misunderstandings or to probe

Table 14: Characteristics of Questionnaire Surveys
(Source: summary of Hussey and Hussey, 1997, and Oppenheim, 1992)

4.2.6 General Criticism of Questionnaire Surveys

Silverman (1985) claims that one of the main weaknesses of questionnaires is the limited ability to provide an understanding and the interpretation of structural factors. However, in order to fully understand social structures, the proper understanding of the processes which influence these social settings have to be known to the researcher.

Zikmund (1994) further counts respondent errors to the survey's disadvantages. There are two respondent related faults, which could occur within a survey: the non-response error and the response bias. Zikmund (1994) understands non-response error as the (statistical) difference between a survey, in which just the questionnaires with responses are considered as opposed to a survey, which also includes those who have failed to respond. Furthermore, amongst those who are responding, a bias may occur. First of all, people may deliberately give false answers or unconsciously misinterpret questions. The first case is similar to the response-bias within interviewing, in which the researcher's influence is rather limited. The second bias, however, can be partially eliminated in face-to-face questionnaire surveys, in which questions can be further clarified and therefore misunderstandings are avoided. However, researchers will find it challenging to eliminate the non-response error, since this would indicate that the response rate of the survey is 100 percent and that the sample comprises the whole population.

4.2.7 Observation

Participant observation is historically seen as the most commonly used method in qualitative research (Gummesson, 2000) and nowadays, participant observation is often applied in management research (e.g. Delbridge, 1998).

The purpose of participant observation is clearly portrayed by Emerson *et al.* (2001). "Participant observation – establishing a place in some natural setting on a relatively long-term basis in order to investigate, experience and represent the social life and social processes that occur in that setting [...]" (Emerson *et al.*, 2001, p.352). There are different types of participant observation. Mason (1996) as well as Nason and Golding (1998) differentiate between the following forms:

- Participant-as-observer (the observed people know about the researcher's purpose)
- Complete participant (the observed people are unaware of the researcher's purpose)
- Observer as participant (a nonrecurring formal observation; mainly observing)
- Complete observer (no social interaction takes place; mainly observing)

Easterby-Smith *et al.* (2002) add a fifth dimension to the above classification, which they describe as 'researcher as employee'. Hereby, the role of the researcher may or may not be explicit. Easterby-Smith *et al.* (2002) claim that this might have an influence on the data collection, as the researcher might not be able to move freely, in cases where colleagues and superiors are aware of the researcher's status. However, being a researcher and an employee has some advantages. It may be the only way to achieve in-depth insights, and is a possibility to "[...] become totally immersed and experience the work or situation at first hand" (Easterby-Smith *et al.*, 2002, p.110).

Participant observation is not one of the main data collection methods within this research, therefore it is only marginally discussed at this place. However, it was necessary to outline the nature and different forms of observation, since within two case studies, the research was undertaken in a way which Easterby-Smith *et al.* (2002) have described as the fifth dimension of participant observation ('researcher as employee'). Within Case One and Two (in Case Company A), the author was employed as intern. In this way, first-hand insights could be gathered, but access to certain data may have been restricted due to confidentiality. However, within the first case study at the

remanufacturing plant, the author applied a different type of observation, which may be termed as 'walking the process'. Hereby, engine parts and components were followed through the individual processes by walking along the recovery and assembly lines. This approach allowed a systematic analysis of process steps, which will be discussed in Chapter Six. This has also provided a very descriptive, in-depth understanding of the (engine) remanufacturing process. Compared to similar, more quantitative research, 'walking the process' has provided very detailed data which presents a starting-point for future, quantitative research in the field. As Section 2.4.2 has already indicated, the immaturity of the field of closed-loop supply chain management, the exploratory nature of the research and this particular approach of visual observation ('walking the process') also explain why much of the data presented in Chapters Six and Seven may seem descriptive, rather than normative.

4.2.8 Data Analysis

In this section, the data analysis tools which were applied in this thesis are presented. In 1979, Miles (1979) explained that more and more researchers focus on qualitative data, due to its beneficial characteristics: qualitative data is perceived as rich, earthy, holistic and 'real' data. However, analysing qualitative data may be very difficult, due to the fact that methods of analysis are not very well formulated (Miles and Huberman, 1994). Easterby-Smith *et al.* (2002) distinguish between two ways of analysing qualitative data: content analysis and grounded analysis. Within content analysis, the researcher tries to quantify qualitative data and counts, for example, how often a particular term has occurred during an interview. There is a variety of software programs to support the so-called 'coding' of the data, which is defined as the creation of categories within grounded theory. Hereby, categories are constructed and developed from the data (Alvesson and Sköldberg, 2000). Software programs include 'The ETHNOGRAPH', 'NUDIST', or 'HyperQual' (Fielding, 2003). These computer programmes aid with the analysis of text data, generated from interviews, (participant) observations, or other documents. 'NUDIST', for example, supports researchers by classifying data into certain categories, such as 'gender issues', 'job satisfaction' or 'human rights'. However, one disadvantage of this content analysis is that it requires verbatim transcripts. Moreover, it is very time-consuming. Within this research, interview data

analysis was therefore undertaken 'manually', in other words, without computer software support.

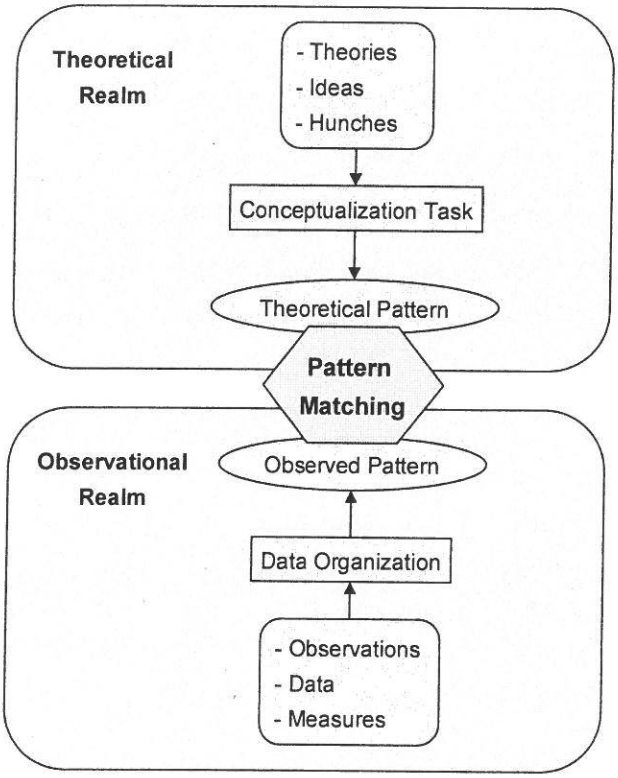


Figure 9: A Technique for Analysing Interview Data: Pattern Matching (Source: reproduced from Trochim, 2002b)

The technique for analysing interview data within this research is termed 'pattern matching' and has been proposed by Trochim (1985, 1989; as shown in Figure 9). Pattern matching has been perceived as an appropriate tool for the data analysis within this research, since it attempts to link two patterns. One pattern is theoretical (formal theory or ideas), the second pattern is based on observation in the form of impressions, field notes or more objective measures (Trochim, 2002b).

Yin (2003) describes pattern matching as one of the most desirable and suitable techniques for case study analysis. For this research, pattern matching was most suitable, since it was applied to compare conceptual ideas (as discussed in Chapters Two and Three) with real-world insights ('walking the process'; interviews) and research findings (Chapters Six, Seven and Eight).

In addition to pattern matching, a reflexive approach was taken. Reflexivity is associated with the phenomenological paradigm, since it is defined as the mutual and continuous affection between the researcher and the object of the study. This is opposite to the positivist paradigm, in which there is no relationship between the researcher and the object which is being researched (Alvesson and Sköldberg, 2000). It is similar to what Charmaz (1983) has defined as 'grounded analysis', in which data collection and analysis are administered simultaneously. Within this research different themes and issues were filtered from the interview transcripts in order to shape the process and products of research, as it was suggested by Charmaz (1983). Moreover, reflection was applied within the data analysis. Easterby-Smith *et al.* (2002) recommend examining if the data supports existing knowledge, if it challenges existing knowledge, or if and how the research may be different from existing knowledge.

4.3 Methodological Considerations within this Research

4.3.1 Justification for Selected Research Strategy and Methods

Case Study Strategy

As previously outlined, the case study strategy is a suitable approach if there is the need to examine phenomena in a real-life context or if there is no clear picture of the phenomena. Yin (2003) further adds that the case study strategy is most appropriate when 'how' or 'why' research questions are asked. Meredith (1998) explains that one of the advantages of case study research is the fact that new variables and relationships which have not been discovered by previous research may be identified. Voss *et al.* (2002) furthermore state that case study strategies are appropriate for testing and applying concepts before they develop into theories. Hence, with regard to the aims of theory-building (Chapter Three) and the real-world insights that are required in order to advance research in the field of closed-loop supply chain management (Chapter Two), the case study strategy was confirmed to be the most suitable strategy for the research problem.

Several factors contributed to the final decision for a case study strategy. Firstly, the field of automotive remanufacturing has been discussed in practitioner circles (e.g. Steinhilper, 1998; Sherwood and Shu, 2000) or within general reports on the remanufacturing industry (e.g. Lund, 1984a, 1984b, 1996). Yet, from an academic perspective, automotive remanufacturing is still badly understood. There have been theoretical discussions, such as by Van der Laan (1997). However, only in the course of the research, more practically oriented, but still quantitative, research was undertaken (e.g. Langella, 2003). In addition, most empirical studies take a North American perspective, such as the work by Lund (1984a, 1984b, 1996) or the survey by Hammond *et al.* (1998).

Secondly, various key contributors within the area of remanufacturing research, such as Guide (2000), Guide *et al.* (1999) and Van der Laan *et al.* (2003) have expressed the need for more case study and survey research. As already pointed out in Chapter Two, Van der Laan *et al.* (2003) have discovered a gap between academic research and current industry practice. Case studies have therefore been perceived as the most adequate type of empirical research in order to bridge this gap (Van der Laan *et al.*, 2003).

Thirdly, due to the characteristics of the automotive remanufacturing industry, as described in Chapter Two, the case study approach seemed to be more promising than a mail questionnaire survey, for example. The automotive remanufacturing sector is characterised by very few large players and many small, independent remanufacturers, who operate on a hand to mouth basis, as outlined by Ferrer and Whybark (2001). With regard to a mail survey, the author anticipated a small response rate, since such small businesses may employ a limited number of people. They may also work on a day-to-day basis while struggling in a competitive environment. Moreover, these businesses are difficult to identify, since they work on a local scale. These assumptions were confirmed within the pilot-phase of the questionnaire, in which the author sought to interview employees in local garages, who were rather reluctant to 'sacrifice' time. These industry characteristics also limited the number of potential case companies, since there are only a few large remanufacturers in Europe. As a result, the author aimed at conducting in-depth case studies.

Ethnographic Interview

The objectives of a specific piece of research have to be clear before a data collection method or its form is selected (Easterby-Smith *et al.*, 2002). With regard to the specific research problem, the design of a mail or face-to-face questionnaire would have been difficult in the initial phase of the research, since the design of specific questions would have been based on few empirical, mainly North American studies. Moreover, the author's understanding of the remanufacturing process and the automotive remanufacturing sector was limited at the onset of the research. Hence, it was decided to

conduct ethnographic interviews as defined by Hammersely and Atkinson (1995), in order to leave room for the interviewer to follow up ideas and clarify certain aspects. In this way, the author's understanding of the subject was increased. Moreover, while conducting the interviews, respondents were free to express their own opinions, beliefs and ideas, which is perceived as a very typical characteristic of case study interviews.

> *...most commonly, case study interviews are of an open-ended nature, in which you can ask key respondents about the facts of a matter as well as their opinions about events. In some situations, you may even ask the respondent to propose his or her own insights into certain occurrences and may use such propositions as the basis for further inquiry. The respondent also can suggest other persons for you to interview, as well as other sources of evidence.*
>
> (Yin, 2003, p.90)

In many cases, new insights from interviewees led to follow-up interviews and hereby formed the nature of the overall research by re-directing it. The transition from engine remanufacturing to electronic device remanufacturing, for example, was entirely based on information given by interviewees, who stated that electronic device remanufacturing was the latest trend within the remanufacturing sector. Section 4.3.4 will further outline the application of ethnographic interviews within this research.

Questionnaire Survey

Although the case study strategy was chosen as the main strategy for this research, the structured interviews which were conducted by means of a questionnaire could be classified as a small-scale survey. The main difference between a case study strategy and a survey strategy can be found in two characteristics: the breadth and the depth of each strategy. Within case research, the unit of analysis is a specific case. As previously outlined, the aim within case research is to obtain a clear and in-depth picture of a particular phenomenon. Consequently, case research is characterised by a low level of breadth, but a high degree of depth.

Within the survey strategy, the same data collection methods may be used as within a case strategy. Trochim (2002e) explains that there are two categories of surveys. The

two most commonly used data collection methods within surveys are the questionnaire and the interview; whereby a questionnaire may provide the basis for the questions in a structured interview.

In this research, the application of the questionnaire survey method had several aims. Firstly, it sought to test and validate the case study results. Secondly, the questionnaire was chosen to supplement, complete and generalise the case study findings. The exploratory case studies provided large amounts of qualitative data. Data collection by questionnaire aimed at generating data through applying a second data collection method, whose findings could be applied to a larger population compared to the specific findings of case research. However, it has to be noted that only in the final phase of the research, the questionnaire was seen as appropriate, since specific themes had developed from the case research. It may therefore be claimed that the research had to commence with the exploratory case study strategy. Only in the descriptive and explanatory phase of the research, observed patterns could be verified and generalised.

The second objective of the questionnaire survey was the generalisation and broadening of patterns which were observed within OEM remanufacturing. The case studies had focused on OEM remanufacturing. The questionnaire therefore targeted further players in the market. For the purpose of achieving an overall understanding of the remanufacturing industry, its market, its players, their motives, as well as the issues and obstacles the individual players face, the questionnaire achieved to obtain supplementary data from the industry as a whole.

4.3.2 Overall Line of Enquiry: Delineation of Scope

In the course of the research, the overall line of enquiry had been re-directed several times. The reasons for each of these changes in direction, such as the migration from car engines to electronics or the deviation from a reverse logistics focus to a closed-loop supply chain focus, will be explained in this section. The research consisted of four phases. From one phase to another, data analysis was undertaken, which is shown by several months of interruption in between the phases of data collection. As previously outlined, the constant interplay between data collection and analysis is a typical

characteristic of grounded theory or the 'constant comparative method' (e.g. Glaser and Strauss, 1967; Strauss and Corbin, 1994) and has been applied throughout the research. Figure 10 gives an overview of the overall line of enquiry and how it has been re-directed. Each of the phases will be discussed afterwards.

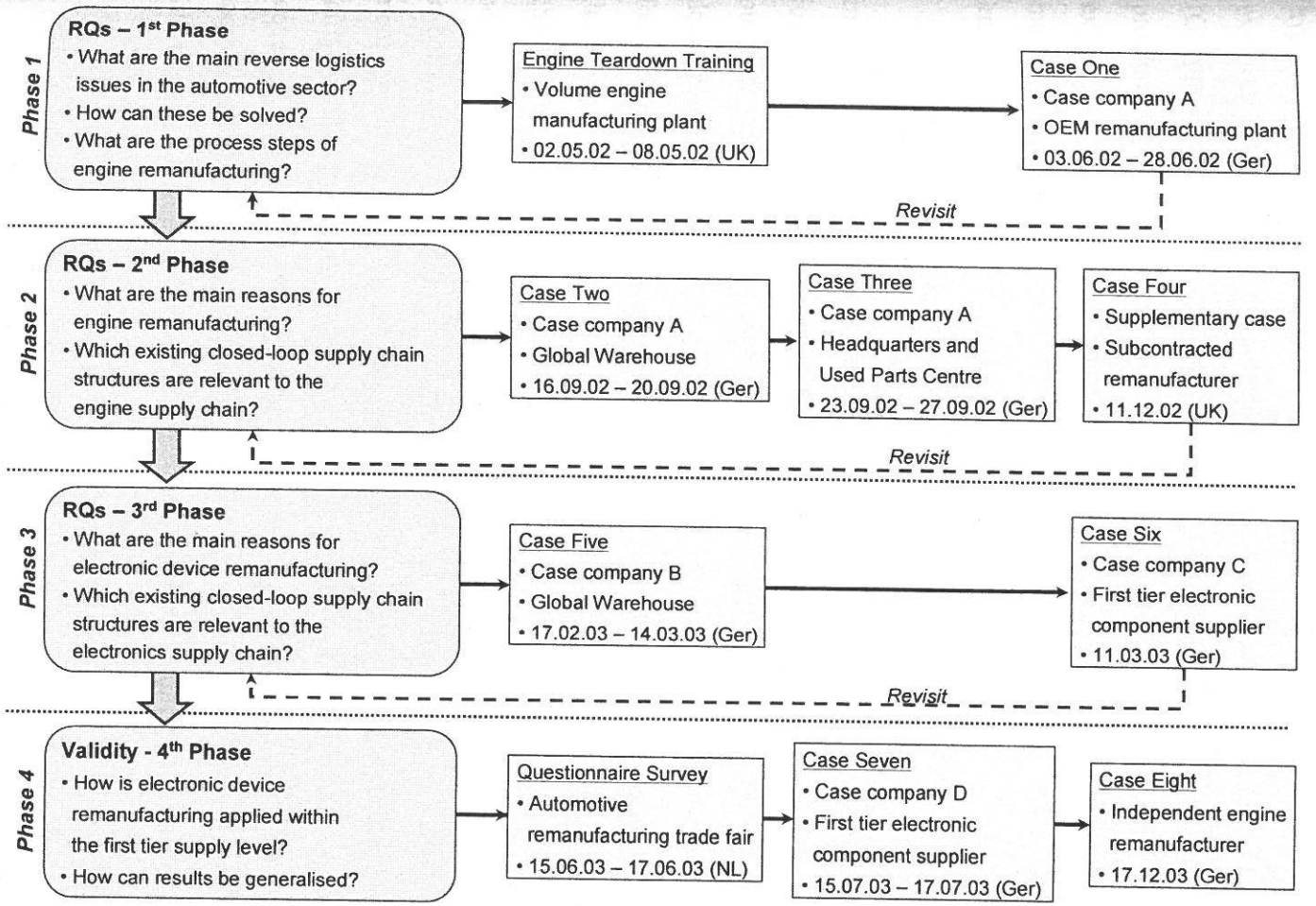


Figure 10: Overall Line of Enquiry and its Re-Direction

Phase One

The research began with a broad idea of what could be described as 'exploratory'. Yin (2003) explains that the main objective of an exploratory study is to develop adequate hypotheses and research questions for further enquiry. As briefly outlined above, exploratory research is characterised by a lack of understanding of the research problem (Ghauri *et al.*, 1995). In comparison to that, in descriptive research, the research problem is well understood and structured. However, research can initially be exploratory, but may become progressively descriptive in the process. Particularly the multiple case study approach supports this argument, as the researcher accumulates knowledge throughout the research process (Yin, 1981a).

In its initial stage, the research took an exploratory approach and focused on reverse logistics only. There were two reasons for that. On the one hand, as Chapter Two has outlined, research in the area of closed-loop supply chain management seems to have developed from reverse logistics research. As a result, initial contributions solely focused on the logistics aspects within the closed-loop supply chain and consequently, there was a vast body on literature on reverse logistics, yet not on closed-loop supply chain management. Secondly, the key contributors in the area of reverse logistics portrayed the field as an area which had just emerged but contained promising potential in both, academia and in industry. Although the area of reverse logistics seems to be more developed than closed-loop supply chain management, it is still considered as a fairly young discipline (e.g. Fleischmann, 2003). Hence, many contributors have requested further empirical research. The author therefore initially centred the line of enquiry around what previous contributions have defined as research needs. The following statements and assumptions had formed the initial line of enquiry.

- Reverse logistics is a new area of research for which only limited publications exist (Rogers and Tibben-Lembke, 1999)
- Awareness for reverse logistics is increasing in various industries (Rogers and Tibben-Lembke, 1999)

- The interest in reverse logistics developed during the 1990s and is becoming increasingly recognised by companies since it can provide a competitive advantage (Stock, J, 1992)
- Most contributions in the area of reverse logistics are descriptive and anecdotal, whereof the majority has appeared in trade publications, not academic journals (Carter and Ellram, 1998)
- As a scientific field, reverse logistics is still young, research results are rather isolated and there is a lack of comprehensive approaches (Fleischmann *et al.*, 1997)
- Current research on reverse logistics lacks to describe 'real world' challenges and does not provide an in-depth understanding of factors which affect reverse logistics activities (Knemeyer *et al.*, 2002)
- There is only a short history of reverse logistics. As a result, there are still many gaps in research (Fleischmann, 2003)

To this point, the specific field was decided upon, but not a specific industry or recovery operation. The decision for automotive remanufacturing was based on several factors. Firstly, there have already been a large number of contributions on other recovery operations, such as recycling.[16]

Consequently, the decision to investigate remanufacturing, rather than any other type of recovery operation, was manifold. First of all, remanufacturing offers high-quality product recovery compared to recycling or re-use. Moreover, remanufacturing operations consist of very extensive and complex operational processes. The focus on this recovery operation is therefore favoured from an operational perspective. In addition, the literature suggests that remanufacturing is expected to become significantly important in various industry sectors, since it may represent an option of meeting environmental, financial and social requirements (Steinhilper, 1998, 1999; Steinhilper and Hudelmaier, 1993). Previous sections (e.g. 2.4.2) have also outlined that

[16] See, for example, Guiltinan and Nwokoye (1975), Ginter and Starling (1978), Cairncross (1992), Pohlen and Farris (1992), Biddle (1993), Steinhilper and Hudelmaier (1993), Brodin (1997), Moyer and Gupta (1997), Knight and Sodhi (2000), Lambert (2001), Wiedemann (2001), Van Hoek (2002), Geyer and Jackson (2004).

remanufacturing is more likely to achieve the ultimate goal of a closed-loop than any other product recovery operation.

Additional delineations had to be made with regard to the industry sector in order to narrow down the scope of this research. The automotive sector was chosen, since research on the remanufacturing of automotive parts has often only been part of larger studies on the remanufacturing industry as a whole (e.g. Lund, 1984a, 1984b, 1996). However, there were few examples of studies focusing on automotive remanufacturing (e.g. Hormozi, 1997; Hammond *et al.*, 1998; Sherwood and Shu, 2000), yet all of them took an American perspective.

Furthermore, research on automotive remanufacturing, not remanufacturing in general, has often been provided for a practitioner audience (e.g. Steinhilper, 1998). There were many examples of research on 'green issues' in the automotive sector, such as extended producer responsibility and end-of-life vehicle take-back (e.g. Ambrose, 2000; Azom, 2003; Deutz, no date given). Research has also been conducted on the remanufacturing of automotive parts and components, but has often been limited to a theoretical discussion (e.g. Van der Laan, 1997).

A further factor which finalised the decision for an automotive perspective, was the upcoming product take-back legislation (ELV Directive) introduced by the European Commission in 2000, which specifically aims to fulfil product recovery targets in the automotive sector and which was generally perceived as a threat within the industry. Various contributors have outlined the impacts of product take-back legislation in general (e.g. Ambrose, 2000; Deutz, no date given; Guide, 2000; Linton, J.D, 2000). Hence, there was the belief that this research would provide support for the automotive industry with regard to the requirements of product take-back legislation. This aspect was further endorsed by the work of Fleischmann (2001), in which he advocates the investigation of end-of-life product returns, since he perceives these as the probably most prominent category of reverse flows.

Due to the fragmentation of the automotive remanufacturing sector which has been previously outlined, it was decided that the first Case Company should be a high-

volume remanufacturing plant. Moreover, there has been research conducted on the independent remanufacturing sector (e.g. Lund, 1984a, Lund, 1996), so that the emphasis on an OEM plant was perceived as beneficial.

The first product group under investigation, passenger car engines, had been selected for several reasons. On the one hand, the car engine was among the first automotive products to be remanufactured (see Section 2.5). Hence, the engine was perceived as the 'classic' candidate for remanufacturing and it was expected that it would provide the researcher with a long history of remanufacturing. The sophisticated level of the engine remanufacturing process was therefore perceived as a suitable starting-point for the research. Moreover, there was the basic assumption that the automotive engine – as one of the most expensive part in the car – is the most profitable aggregate to recover. There was no initial intention to prefer passenger car engines over commercial vehicle engines. However, it became clear that a focus on the passenger car sector would be more beneficial since the commercial vehicle sector seemed to be less researched, given the smaller amount of secondary data which was available.

With the choice for a recovery plant, also the decision for a place of enquiry was restricted. Conducting the research in Germany, as the 'host country' of various OEM engine remanufacturing plants was also beneficial with regard to the proximity, access and language barriers. However, since most of the research was undertaken in that country, the process of translating interviews and further information may have distorted some aspects within the research.

Phase Two

The first case study was followed by an analysis of the data as it is requested within 'grounded theory'. As a result, the interplay between data analysis and data collection led to the first re-alignment and a re-focus of the research. Within the first case study, it became clear that the issues within reverse logistics management which had been filtered from the literature (see Chapter Two) were not perceived as relevant in Case Company A, since it used the forward distribution network as reverse collection channel. Consequently, the issue about obstacles in reverse logistics, such as the

integration of forward and reverse flows or the ideal channel network setup, as it had been widely discussed in the literature (e.g. Fleischmann *et al.*, 1997; Krikke, 2001; Knemeyer *et al.*, 2002) was not applicable to the first case.

Interviewees also reacted surprised on questions regarding the ELV Directive. They had not thought about a relationship between remanufacturing and environmental legislation. As a result, the author began to question the general assumptions within the literature. A good case in point were the economic benefits of remanufacturing which had been pointed out by previous contributors. The question arose, if neither specific automotive take-back regulation nor economic benefits have caused or at least encouraged the establishment of automotive remanufacturing plants, which factors did? Moreover, it became clear that the investigation had to embrace the closed-loop supply chain as a whole, rather than examining reverse logistics only. It therefore seemed as if previous research had focused too narrowly on the optimisation of specific operational issues, which had been criticised by Guide *et al.* (2003b). However, despite being the major cause for the re-direction of the overall research, the first case study contributed to the understanding of the author's knowledge on mechanical remanufacturing operations.

Since the need for a holistic perspective of closed-loop supply chain management became apparent within the first case study, the second phase of the research investigated two more cases from the same vehicle manufacturer. Case two comprised a visit to the Global Warehouse, which stores the engines that are remanufactured by the first Case Company. In this way, the overall flow of cores and remanufactured engines could be understood and displayed. This was necessary, since interviewees within the first case were not fully aware of the practices elsewhere. Moreover, the third case gave insights into the overall aftermarket parts management and the financial side of engine remanufacturing. In the course of these two cases, interviewees noted that electronic device remanufacturing was perceived as the 'latest trend' in the remanufacturing sector, an aspect, which further shaped the direction of the research.

The last case in phase two comprised a field visit to a major UK-based subcontracted engine remanufacturer, in order to verify certain aspects within the engine

remanufacturing operation. Moreover, the author sought to clarify if practices at other major engine remanufacturing plants were of the same nature that what had been observed in the first Case Company.

Phase Three

The second phase of the research was followed by a further re-adjustment of the direction of the research. Since interview results within the second phase had diverted the research towards the latest trend in the sector, the remanufacturing of electronic components, the author decided to investigate electronic device remanufacturing from a vehicle manufacturer's perspective. The decision to return to the vehicle manufacturer's facilities had also been influenced by the facilitated access, which was given through the previous research visits. Moreover, the author aimed at developing further contacts to the original manufacturers of electronic components, the first tier suppliers, which could be achieved from an 'insider' position. The data obtained on electronic device remanufacturing was significantly different to the information gathered on engine remanufacturing. Hence, there was not only a transition within the product focus of the research from engines to electronics, but also a change in the nature of the data. Data obtained within the electronics case studies was more qualitative, since this remanufacturing operation had only been introduced in the late 1990s. However, Chapter Seven will further outline the differences between the engine and the electronics remanufacturing case studies.

Phase Four

After a third analysis of the data, there was the need to obtain data from the rest of the automotive remanufacturing industry, the independent remanufacturers. The findings and results from the case research as well as from the literature on remanufacturing provided the basis for the questions within the questionnaire. The aim hereby was to obtain a more general picture of the industry. Moreover, in this last phase of the research, the research on electronic device remanufacturing was finalised. It became clear that additional field visits would only contribute marginally to this research, hence

it was decided to conclude the data collection. Robson (2002) confirms that at this point, grounded research is destined to end.

> *Visits continue until the categories found through analysis are 'saturated'. Or, in other words, you keep on gathering information until you reach diminishing returns and you are not adding to what you already have.*
>
> (Robson, 2002, p.192)

Case Companies

Tables 15 and 16 characterises the case companies that were most relevant to the research. Furthermore, their positions in the supply chain as well as their relevance to this thesis are outlined.

	Case Company A (focus: engines)
Description	Major vehicle manufacturer
Position in the supply chain	▪ Case One: The remanufacturing echelon of the closed-loop supply chain (engine remanufacturing plant) ▪ Case Two: The distribution echelon of the closed-loop supply chain (Global Warehouse ▪ Case Three: Administrative Headquarters
Relevance to the thesis	▪ Chapter Five: The remanufacturing process and the European remanufacturing market; characteristics of engine manufacturing; increasing the author's knowledge of the automotive aftermarket ▪ Chapter Six: Specific remanufacturing process data; development of the closed-loop supply chain structure for engine remanufacturing ▪ Chapter Seven: Providing new ideas and trends for the re-direction towards electronics remanufacturing ▪ Chapter Eight: Providing case study results and findings for the development of the questionnaire ▪ Chapter Nine: In-depth discussion of the structure of closed-loop supply chains for engines ▪ Chapter Ten: Providing findings for the motives that induce automotive remanufacturing

	Case Company B (focus: electronics)
Description	Major vehicle manufacturer
Position in the supply chain	▪ Case Five: The distribution echelon of the closed-loop supply chain (Global Warehouse)
Relevance to the thesis	▪ Chapter Five: Outlining the differences between engine and electronics remanufacturing; characteristics of electronic device manufacturing; increasing the author's knowledge of the automotive aftermarket ▪ Chapter Seven: Specific information and data on electronics remanufacturing; development of the closed-loop supply chain structure for electronic device remanufacturing ▪ Chapter Eight: Providing case study results and findings for the development of the questionnaire ▪ Chapter Nine: In-depth discussion of the structure of closed-loop supply chains for electronic devices ▪ Chapter Ten: Providing findings for the motives that induce automotive remanufacturing

Table 15: Description of Main Case Companies and Relevance to the Research – Part 1

	Case Company C (focus: electronics)
Description	Major first tier supplier for electronic devices
Position in the supply chain	▪ Case Six: Manufacturing and remanufacturing echelon in the electronics (closed-loop) supply chain
Relevance to the thesis	▪ Chapter Seven: Specific information and data on electronics remanufacturing; development of the closed-loop supply chain structure for electronic device remanufacturing ▪ Chapter Eight: Providing case study results and findings for the development of the questionnaire ▪ Chapter Nine: In-depth discussion of the structure of closed-loop supply chains for electronic devices ▪ Chapter Ten: Providing findings for the motives that induce automotive remanufacturing

	Case Company D (focus: electronics)
Description	Major first tier supplier for electronic devices
Position in the supply chain	▪ Case Seven: Manufacturing and remanufacturing echelon in the electronics (closed-loop) supply chain
Relevance to the thesis	▪ Chapter Seven: Specific information and data on electronics remanufacturing; development of the closed-loop supply chain structure for electronic device remanufacturing ▪ Chapter Eight: Providing case study results and findings for the development of the questionnaire ▪ Chapter Nine: In-depth discussion of the structure of closed-loop supply chains for electronic devices ▪ Chapter Ten: Providing findings for the motives that induce automotive remanufacturing

Table 16: Description of Main Case Companies and Relevance to the Research – Part 2

4.3.3 Specific Line of Enquiry: Interview Structure, Process and Analysis

The aim of this section is to portray, outline and explain how interviewing, as the main method of data collection, was applied within this research. The previous sections have identified the characteristics, merits and weaknesses of interviewing as a data collection method. This section outlines the interview process in more detail by presenting the interview protocol, the distribution of interviews at each of the four research phases (see Figure 10) and an audit trail of how conclusions were drawn from the interviews.

Application of Ethnographic Interviews for Data Collection

Section 4.2.3 has outlined the different forms of interviewing and their characteristics. Most researchers distinguish between structured and unstructured interviews, as defined in section 4.3.1. Hammersley and Atkinson (1995), however, differentiate between standardised and reflexive interviews.

> *The important distinction to me made is between standardized and reflexive interviewing. Ethnographers do not usually decide beforehand the exact questions they want to ask, and do not ask each interviewee exactly the same questions, though they will usually enter the interviews with a list of issues to be covered. Nor do they seek to establish a fixed sequence in which relevant topics are covered; they adopt a more flexible approach, allowing the discussion to flow in a way that seems natural.*
>
> (Hammersley and Atkinson, 1995, p.152)

Hammersley and Atkinson's definition of the ethnographic interview describes the main form of interview applied within this research. Section 4.3.1 has already touched on the advantages of the ethnographic interview within this research, including the increase of the author's understanding of automotive remanufacturing in the initial stages of the research as well as the flexibility to uncover new insights. In addition, within this research, interview questions were open-ended. According to Zikmund (1994), interviewees respond to open-ended questions by using their own words. In other words, the interviewer does not propose a set of specific alternative responses. This stands in contrast to closed questions, in which interviewees choose the response suggested by the interviewer that is closest to their opinion. Again, the advantage of open-ended

questions is the fact that new clues may be uncovered. Chapter Two has demonstrated that the automotive remanufacturing sector has been neglected within academic research. As a result, open-ended and non-directive questions were perceived as most beneficial to increase the understanding of automotive remanufacturing as well as to uncover new insights that were expressed by interviewees. Zikmund (1994) confirms that open-ended response questions are most suitable if the full range of responses is not known. This approach to interviewing has influenced this research positively in various ways. Firstly, specific remanufacturing and automotive terminology was learned. Secondly, interviewees pointed out where further information could be obtained by recommending additional interviewees/colleagues. Thirdly, latest remanufacturing trends, for example the remanufacturing of electronic devices, have been pointed out by interviewees and have significantly shaped this research (see also Section 4.3.2). To sum it up, the key characteristic 'flexibility' of the ethnographic interview has been addressed within this research in two ways. Firstly, interviews were entered with a list of key questions or main issues to be covered (see right hand columns in Tables 17 to 30). Secondly, there was a high degree of flexibility for respondents in the form of open-ended, non-directive interview questions.

A complete list of interviews can be found in Appendix F. Further key interviews are displayed in full length in Appendix G. The following sections demonstrate how these interviews were distributed at the different research phases of Figure 10 (specific indication of the number of interviewees from Appendix F that were interviewed within the companies; left hand columns of Tables 17 to 30), the questions that were asked and the key research issues and aims that were investigated within the four phases. In addition, the tables in the following sections present additional information on data collection, such as process observation that was undertaken ('walking the process') and secondary or archival data obtained from interviewees.

Phase One: Interview Questions, Key Research Issues and Aims

The interview questions presented within this section (Tables 17 to 19) correspond to the case companies visited in the first phase of the research (see Figure 10). Section

4.3.2 has already briefly outlined the exploratory nature of the first research phase. This section elaborates on the interview questions, interview process and aims in more detail. One of the key research aims of the first company visit (high-volume engine manufacturing plant) was to increase the author's understanding of the engine as a product, the engine manufacturing process as well as material and product flows accompanying the manufacturing process. Within this thesis, this field visit only provided background information (see Chapter Five), but is not referred to in the results Chapters Nine and Ten. For reasons of simplification it has therefore not been identified as a (relevant) case company as such. Table 17 presents the main questions posed during interviews within the facilities of the first company. Due to the flexibility of the ethnographic interview, certain aspects that occurred during the interviews may have been followed up spontaneously and may therefore not necessarily be listed in Table 17 in much detail.

Tables 18 and 19 outline the distribution of interviews within the first case study relevant to answering the research questions. The main aims within Case One, which was conducted during a four-week stay in a VM remanufacturing facility (see Chapter Six) refer to the overall understanding of engine remanufacturing, obstacles and issues within these operations as well as a comprehension of OEM working practices. Particularly relevant to answering Research Questions 1 and 2 were questions relating to reverse logistics, logistics processes within the plant and information/data about individual remanufacturing process steps (see Table 18). The key questions have been displayed in Table 18, however, further, minor questions occurred during interviews in order to clarify or follow up certain aspects.

With regard to Research Questions 3, 4 and 5, interviewees were asked in a non-directive, open-ended form as previously outlined. Questions were therefore openly phrased as:

- What are the motivations for your company to provide exchange parts?
- What are the main reasons for the company to undertake engine remanufacturing?

The idea behind this way of enquiry was not to limit answers to certain categories. In addition, due to a potential lack of the author's understanding, the full range of answers may not have been covered through closed questions. Punch (1998) confirms: "It [the ethnographic interview] is used as a way of understanding the complex behaviour of people without imposing any *a priori* categorization which might limit the field of inquiry" (p.178).

Only after the interviewees had responded to the first set of questions (open-ended, non-directive) further, more specific enquiries were made with regard to testing the main motives for remanufacturing as outlined in the literature:

- Which role does environmental legislation, such as the ELV Directive, play as a motive for engine remanufacturing?
- What is the main customer group for remanufactured engines? Is there something like the 'green' or 'ethical' customer?
- Is the engine remanufacturing operation profitable? If yes, is profitability one of the main reasons why this company engages in engine remanufacturing?

Table 19 further summarises additional data collected within Case One of Case Company A.

Company Description	Questions	Key Research Issues
▪ High-volume engine manufacturing plant: engine evaluation lab ▪ Interviewees 2 to 5 and 7 to 10 (Appendix F); In addition: workers at the assembly lines	▪ Which companies are your main customers and suppliers? ▪ Please explain the general assembly and machining process ▪ What is the lead time for a whole engine, the cylinder head and engine block? ▪ What volumes are produced per engine family? ▪ What percentage of the production volume is destined for the aftermarket? ▪ What materials are used for the main engine parts (cylinder head, block, crankshaft, camshaft, connecting rods, pistons, valves)? ▪ What are the material costs for one engine? ▪ Can you provide me with a list of all parts making up one engine? ▪ Which engine parts can be remanufactured? ▪ Which companies provide remanufacturing services to this VM? ▪ How significant are the (financial) savings made by the repair of parts that fail the (quality) test on the assembly line - a service which is provided by a remanufacturer? ▪ What are the different recycling/remanufacturing paths for engines or engine parts that were used in the engine evaluation lab (quality audit)? ▪ What determines the remanufacturability of an engine block, for example?	▪ Understanding composition and functionality of car engines ▪ Understanding the engine manufacturing process

Process Observation
▪ Hot-test observation of one standard engine (1 hour); comparing engine performance with expected/standard performance ▪ Complete disassembly of one engine and analysis of parts with regard to wear, missing, damaged or non-functional parts; rating of errors into four categories (minor to critical faults ▪ Engine assembly ('walking the process'; mapping the process) ▪ Cylinder head assembly ('walking the process'; mapping the process) ▪ Machining of camshafts, connecting rods, crankshaft, ladder frame, cylinder head, engine block ▪ Piston assembly

Secondary/Archival Data
▪ Complete catalogue of engine evaluation specifications ▪ Engine parts lists

Table 17: Specific Line of Enquiry in Research Phase One (Engine Manufacturing Plant)

Company Description	Questions	Key Research Issues
▪ Case Company A ▪ Case One ▪ OEM Remanufacturing Plant ▪ Interviewees 6, 12 to 45 (Appendix F)	▪ Please give a brief outline of the company structure, i.e. number of employees, remanufacturing activities undertaken, position within the group, history etc. ▪ Which processes/activities are taking place within each part of the remanufacturing operation (i.e. core warehouse, disassembly and cleaning, identification and control, chemical cleaning, quality control, parts recovery, engine re-assembly, cold test/hot test) ▪ What are the lead times for above process steps? ▪ Have you observed any inefficiencies/obstacles/issues within these processes? If yes, how may these be solved? ▪ How is the remanufacturing plant integrated into the whole exchange process? Where do engines cores originate from and to where are they transported after remanufacturing? ▪ The literature often suggests issues within the reverse logistics processes. What obstacles has your company been faced with? If there are obstacles, what countermeasures are applied? ▪ How much stock can be found in the core warehouse and in the parts warehouse? What is the value of the inventory? What are the main factors leading to excessive inventory levels? ▪ How do you plan the remanufacturing process? Please explain all the relevant steps from receiving the order, recovery planning up to packaging and shipment with all relevant process steps in between. ▪ What computer system is used for planning the above processes? ▪ Are there any sales to customers directly or are all engines distributed via the retailers? ▪ What are the obstacles to remanufacturing? Are there technical limitations, reservations from customers or similar issues that may threaten the future of engine remanufacturing? ▪ How do you see the future of engine remanufacturing? ▪ What are, generally, the motivations for your company to provide exchange parts? ▪ What are the main reasons for the company to undertake engine remanufacturing? ▪ Which role does environmental legislation, such as the ELV Directive play as a motive for engine remanufacturing? ▪ What is the main customer group for remanufactured engines? Is there something like the 'green' or 'ethical' customer'? ▪ Is there a profitability analysis per engine model? Is the engine remanufacturing operation profitable? If yes, is profitability one of the main reasons why this company engages in engine remanufacturing?	▪ Understanding the engine remanufacturing process (operational perspective) ▪ Understanding OEM working practices ▪ Understanding the product (engine) ▪ Understanding major issues and obstacles within remanufacturing and how these may be overcome

Table 18: Specific Line of Enquiry in Research Phase One (Case Company A; Case One) – Part 1

Process Observation
▪ Investigating processes within the core warehouse, inventory strategies, issues and obstacles within core management. ▪ Observation of processes included in the engine disassembly process and the sorting of parts for cleaning in the 'washing machine' ▪ Observation of identification and control processes and the distribution/sorting of parts for further processing thereafter ▪ Observation of chemical cleaning (as far as possible) ▪ Observation of the quality control processes before recovery ▪ Observation of recovery of main engine parts: cylinder block, cylinder head, crankshaft, camshaft, connecting rods and smaller parts, such as valves ▪ Observation and mapping of the engine re-assembly process ▪ Observation of engine cold and hot testing ▪ Mapping the whole process flows of engine key parts: cylinder block, cylinder head, crankshaft, camshaft, connecting rods from step one (disassembly and cleaning) to the last step (cold test/hot test, packaging and shipment)

Secondary/Archival Data
▪ Generic information about the plant ▪ Production volumes new and remanufactured engines ▪ Sales volumes per engine model (remanufactured) ▪ Parts catalogue for one engine model ▪ Various internal company reports on logistics processes within the plant; written by temporary employees, such as interns and students ▪ Company A: Remanufacturing Handbook ▪ Internal company report: reduction or delivery times for remanufactured engines (Powerpoint presentation by the centre manager) ▪ Key to engine/vehicle classification: which type of engines are installed in which car models ▪ Batch sizes of engine remanufacturing for 2001 ▪ Technical remanufacturing instructions as specified by the group ▪ Further data, partially displayed within Chapter Six

Table 19: Specific Line of Enquiry in Research Phase One (Case Company A; Case One) – Part 2

Phase Two: Interview Questions, Key Research Issues and Aims

The focus of the interviews within Research Phase One evolved around the logistics processes of product take-back, logistics within the remanufacturing plant as well as product distribution after recovery. However, in the course of the first case study, it became clear that certain assumptions from the literature could not be applied to the automotive sector. In particular, this referred to the applicability of closed-loop supply chain models (as outlined in Chapter Two) and the motives for product take-back and recovery (Chapter Three). After the analysis of data from Research Phase One, the second visit to Case Company A aimed at further clarifying and verifying those initial observations as well as obtaining information on questions that previous respondents could only answer insufficiently.

The first case study visit within Research Phase Two (Tables 20 and 21), the Global Warehouse, aimed at clarifying the collection and distribution structures in which the company's remanufacturing plant was integrated. Moreover, the interviews sought to identify the role of remanufactured products within the aftermarket supply strategy and the company's main motives for providing an extensive product range of remanufactured products. Further key aspects were investigated (see Table 21). Within this case study, the latest trend of electronic device remanufacturing was discovered and contacts for future field visits were established.

Case Three included Case Company A's Headquarters as well as the Used Parts Centre. Several key respondents were interviewed at this stage, including interviewees within the controlling department (price-building) and product managers for remanufactured parts and life cycle management. The contacts had been established through interviewees at the Global Warehouse as these strongly co-operated with employees at the Headquarters. Interview questions were similar to the questions posed in the previous case study, however, more emphasis was put on aftermarket aspects and pricing (see Table 22). The visit to the Used Parts centre aimed at investigating the relevance of the ELV Directive for the case company. Within the industry, the ELV Directive was generally seen as a threat. The Used Parts Centre also comprised an ELV

dismantling facility. Through the enquiry of product and part flows related to ELV return and dismantling, the author sought to identify whether there was a relationship between end-of-life vehicle treatment and remanufacturing (e.g. whether remanufacturing plants obtain cores from dismantling centres). However, within Company A, no relationship was found.

The last case study within Research Phase Two, Case Four, comprised a visit to the engine remanufacturing facilities of a UK based subcontracted remanufacturer. Table 24 summarises the key questions that were asked at this field visit. The key aims were to verify (process) observations from Research Phase One (Case One), in particular with regard to similarities and/or differences between the working practices of OEM engine remanufacturers and subcontracted remanufacturers. Various observations from Research Phase One could be confirmed, such as the high degree of manual labour within remanufacturing, high core inventory and high lead times for specific process steps. In addition this visit provided the opportunity to clarify certain aspects within the recovery process through an observation of the engine remanufacturing process ('walking the process'; mapping the process).

Company Description	Questions	Key Research Issues
▪ Case Company A ▪ Case Two ▪ Global Warehouse ▪ Interviewees 46 to 63 (Appendix F)	▪ Please give a brief outline of the company structure, i.e. number of employees, activities undertaken, position within the group, history etc. ▪ Please describe the retailer and distribution network of the company. What are the return flows of cores? How are remanufactured products distributed? How are financial flows (e.g. rebate) handled within the company? ▪ Do retailers (subsidiaries and franchised dealers) return the cores directly to the remanufacturer? How many cores return on a weekly basis? ▪ From which countries do most of the engines return (figures)? ▪ What are the logistics costs involved with core collection, transportation to the remanufacturing plant and distribution of remanufactured engines? Can those processes be combined with other products? ▪ What are the issues involved in the return process? What countermeasures are applied to avoid these? ▪ How many (finished) remanufactured engines are on stock? Why are stock levels so high for the remanufacturer, but also within the Global Warehouse? ▪ How is the Global Warehouse managed? What are the different phases of spare parts/aftermarket management and what issues may occur within the aftermarket management? ▪ Can you provide me with a price and cost comparison between remanufactured and new engines? How is the rebate calculated/on what factors does it depend? ▪ How does the company calculate the prices for the remanufactured engines? How much profit is made? Is profitability one of the main reasons for the company to remanufacture? ▪ How much does the end-customer pay for the engine? Why so much? ▪ Why does the company want to avoid that cores divert into the 'grey market'? Why is an engine core so demanded/ valuable within the 'grey market'? ▪ What are the advantages and what are the disadvantages of remanufactured products? ▪ Why is the long-term supply of electronic devices considerably more challenging than the long-term supply of mechanical components? ▪ Demand forecasting: how is it undertaken? What problems are involved in the forecasting of aftermarket spare parts demand?	▪ Following up issues/questions discovered in Phase One ▪ Understanding reverse logistics flows and product flows along the supply chain ▪ Understanding aftermarket management and the supply of spare parts over an extended period of time (supply strategies) ▪ Understanding company's motivations for providing an extensive exchange programme

Table 20: Specific Line of Enquiry in Research Phase Two (Case Company A; Case Two) – Part 1

Company Description	Questions (Continued)	Key Research Issues
▪ Case Company A ▪ Case Two ▪ Global Warehouse ▪ Interviewees 46 to 63 (Appendix F)	▪ How strong is competition in the aftermarket? What is the role of the Block Exemption Regulation and which impact will it have on the company? ▪ Why does the company provide an aftermarket exchange programme? What are the company's main reasons to engage in these activities? ▪ Which role does environmental legislation, such as the ELV Directive play as a motive for remanufacturing? ▪ What is the main customer group for remanufactured car engines? Is there something like the 'green' or 'ethical' customer? ▪ At what point in time of an engine lifecycle does remanufacturing product begin? Do you have any information on manufacturing/remanufacturing life cycles of engines? ▪ Product variety has been identified as a major obstacle to remanufacturing. Why are there so many engine variants how do these occur? What impact does product variety have on aftermarket management?	▪ Following up issues/questions from Phase One ▪ Understanding how remanufactured parts fit in with the overall aftermarket management structure

Secondary/Archival Data
▪ Report on company structure, activities, function within the group, etc.
▪ Figures on 'parts explosion', the increase of part numbers and capital bound in stock within aftermarket warehouse management
▪ Internal market report: the market of remanufactured engines throughout Europe: market players, competition, prices, threats
▪ Spreadsheets on engine variants and prices
▪ Various reports on operations within vehicle and truck manufacturing plants

Table 21: Specific Line of Enquiry in Research Phase Two (Case Company A; Case Two) – Part 2

Company Description	Questions	Key Research Issues
▪ Case Company A ▪ Case Three ▪ Headquarters ▪ Interviewees 64 to 69 (Appendix F)	▪ Please give a brief outline of the company structure, and its position within the group ▪ Why are engines being remanufactured and why did the company set up a remanufacturing plant in 1986 when there hasn't been any environmental regulation, such as the ELV Directive? ▪ What are the main reasons for engine remanufacturing? What role does environmental responsibility or the ELV Directive play in this respect? ▪ What are the main reasons for the company to now focus on the remanufacturing of electronic devices? ▪ Why are remanufactured engines not installed into new cars? What if a very recent engine model is being remanufactured, a model that is still being built into new cars? ▪ The market for remanufactured engines seems to be quite small: mainly professionally used vehicles receive remanufactured engines. Would private customers (non-commercial car users) install a remanufactured (good as new) engine into an old vehicle? ▪ How are remanufactured products distributed (clarifications needed from Phase One)? How does the supply chain of new engines look like (map supply chain)? ▪ Is the ELV Directive only an issue for mass car producers and not so much for luxury car manufacturers? ▪ Why is there such a high demand for engine cores and why does the company pay so much rebate for cores? ▪ Are there any figures about other remanufactured products, such as figures about sales in different countries: gearboxes, smaller parts etc.? ▪ How much does a new engine cost in comparison to a remanufactured engine? ▪ How many engine variants are there and why are there so many? ▪ What are the differences between engine variants? Do they share certain parts, such as the cylinder block? ▪ Direct demand from customers: how does the company undertake demand forecasting? What are the issues involved in developing reliable forecasts? ▪ What are the main issues involved within the long-term supply of spare parts? How can these overcome and what countermeasures are being applied by the company? ▪ Serial thinking versus aftermarket thinking: what are the implications for 'design for environment'? Is there an information flow between engine designers and remanufacturers?	▪ Following up issues/questions discovered in Phase One ▪ Understanding company's motivations to provide an exchange programme ▪ Understanding aftermarket management strategies and the role of remanufactured parts ▪ Understanding the remanufacturing market, players, competition, main issues, etc.

Table 22: Specific Line of Enquiry in Research Phase Two (Case Company A; Case Three) – Part 1

Company Description	Questions	Key Research Issues
▪ Case Company A ▪ Case Three ▪ Used Parts Centre ▪ Interviewees 70 to 72 (Appendix F)	▪ What are the different sources for End-of-Life Vehicles (ELVs)? ▪ Do customers have to pay for ELV treatment? Does the company also pay for residual values of ELVs? ▪ Which product flows occur for parts that may be remanufactured, such as gear boxes, engines, smaller motors, electrical components, electronic devices? ▪ Is there a return flow to Case Company A's engine remanufacturing plant? If not, what happens to engines from ELVs? ▪ How much (in percent) of an ELV is scrapped? ▪ What were the company's main reasons to establish the Used Parts Centre? ▪ How many parts are on stock? How is the inventory managed? ▪ Is there a relationship between the ELV Directive and remanufacturing? If yes, in which ways? ▪ Is ELV treatment profitable? What other services does the centre provide? ▪ Who are the main customers? ▪ What is the warranty for the used parts?	▪ Understanding the relationship or link between the ELV Directive and remanufacturing ▪ Aiming to identify further sources of cores ▪ Understanding the breadth and diversity of aftermarket spare parts management

Secondary/Archival Data
▪ Internal reports on the strategic management of parts supply within the aftermarket ▪ Engine production per manufacturing plant ▪ Internal company report: lifecycle management (parts management across the whole car lifecycle) ▪ Report on products, activities and figures of Used Parts Centre

Process Observation
▪ Observation of ELV dismantling, sorting of parts and scrapping ▪ Observation of used parts storage (inventory management) and parts flows

Table 23: Specific Line of Enquiry in Research Phase Two (Case Company A; Case Three) – Part 2

Company Description	Questions	Key Research Issues
▪ Case Four ▪ Subcontracted Remanufacturer ▪ Interviewees 76 to 78 (Appendix F)	▪ Please give a brief outline of the company structure, its activities, number of employees, etc. ▪ What has initiated the establishment of your company? What role did environmental regulations play? What is the history of your company? ▪ How does the product range look like? How many engines are remanufactured per year? Apart from remanufacturing, does the company undertake further services? ▪ Product range: How many engine variants are remanufactured? How old are these engines? Does engine variation have an impact on the recovery process? How can obstacles be overcome? ▪ What is the relationship to the main customer (VM)? Is there an information flow back to the VM, with regard to product design, for example ('design for environment')? ▪ Inventory issues: How is the inventory managed? Does and increase in engine variants have an impact on stock management? ▪ Logistics aspects: How do engine cores get to the plant for remanufacturing? What type of logistics network is used? Which supply chain echelons are integrated in the process: dealers, the VM? ▪ Financial aspects: How much is paid for the core? Can the customer buy an engine without returning a core? ▪ Financial aspects: Is engine remanufacturing profitable? Which engine type/model is the most profitable? Do market prices (i.e. the competitors' prices) influence pricing? ▪ What are the main reasons for undertaking engine remanufacturing? Is there a difference to engine remanufacturing undertaken by the VM or remanufacturing in VM facilities? ▪ Who owns the cores? Are there any other streams/flows of products, e.g. for recycling? ▪ What are the lead times for individual processes and how much work in progress is kept? How much scrap accumulates per engine? ▪ How long does it take to re-assemble the engine and how is the remanufacturing process organised? ▪ Does the VM undertake demand forecasting? ▪ Is engine remanufacturing a decreasing business? Who are your main competitors?	▪ Following up issues/questions discovered in Phase One ▪ Verification of observations and findings within Phase One ▪ Aiming to identify the differences and similarities between OEM and subcontracted remanufacturers

Process Observation
▪ Observation of engine remanufacturing activities undertaken by a Subcontracted remanufacturer ▪ Observation of parts and materials flows as well as inventory levels

Table 24: Specific Line of Enquiry in Research Phase Two (Case Four)

Phase Three: Interview Questions, Key Research Issues and Aims

Research Phase Two was followed by data analysis and a re-evaluation of the line of enquiry. Literature was reviewed with regard to new observations, such as the remanufacturing sector's increasing interest in electronic device remanufacturing.

The first case study within Research Phase Three involved a four-week stay at Case Company B's Global Warehouse. During this time, the author had the opportunity to work with employees on a newly established project for electronic device remanufacturing and the development of aftermarket strategies to ensure the long-term supply of electronic devices. The main aim within this field visit was to identify differences and similarities between mechanical and electronic remanufacturing. Furthermore, contacts with electronic suppliers were established for further field visits. In addition, the author sought to enquire similar aspects for electronic devices as the previous research phases had investigated for car engines. Examples include the core collection process, the recovery process as well as the product distribution after recovery. A particular emphasis was also put on the motives for electronic device remanufacturing. As it was found, these differed slightly from the motives for engine remanufacturing. Again, an open-ended, non-directive form of questioning was applied, as the author did not seek to limit the breadth of potential responses. Questions were also re-phrased and repeatedly asked in order to increase the validity of responses (see Tables 25 and 26).

In the course of Case Study Five, contacts were established with Case Company C (Case Six) which was followed by a visit to this company's electronic device manufacturing and remanufacturing facilities. The main objective of Case Six was to observe the aspects learned within Case Five in practice. Questions therefore evolved around the practical understanding of electronic device manufacturing and remanufacturing operations (Table 27). The aim was to obtain similar information for electronic device remanufacturing as it was collected within Case One (engine remanufacturing). With regard to Research Questions 1 and 2, the enquiry evolved around the identification of the closed-loop supply chain and the remanufacturing

processes for electronic devices. In addition the supplier's motives for engaging in the remanufacturing of electronic devices were examined. Chapter 7 demonstrates how these differ from the vehicle manufacturer's rationale for remanufacturing.

Company Description	Questions	Key Research Issues
▪ Case Company B ▪ Case Five ▪ Global Warehouse ▪ Interviewees 82 to 111 and 113 to 117 (Appendix F)	▪ How many different routes can be found in the collection network structure for remanufactured parts? How often are cores collected (daily, every second day)? ▪ Is there a difference between core collection from a subsidiary and core collection from a franchised dealer or are both parties treated equally? ▪ Is it possible to determine the logistics costs for one remanufactured product or are these costs embedded in the overall costs for logistics service providers? ▪ What are the differences between electronic device remanufacturing and the remanufacturing of mechanical components? ▪ Electronics remanufacturing: what is the company's relationship with car dealers and dismantlers? How do they know what to do with cores? Which information is given to the retail level? ▪ How doe retailers/the company decide which electronic devices are valuable? What happens with products produced by a supplier or competitor? Which electronic devices can be remanufactured? ▪ What are the company's motives for the take back and remanufacturing of electronic devices? Which role does the ELV Directive play in this respect? Which role does the WEEE Directive play? ▪ Is there a 'green' consumer for remanufactured electronic devices? ▪ Are electronic devices remanufactured on-site (e.g. within the facilities of the dealer or the garage) or is there a central remanufacturing facility? Which suppliers are involved in remanufacturing? ▪ Which devices go back to the suppliers? (Note: this is different with engines, as these are usually manufactured by the VM. Electronic devices, however, are supplied) ▪ Is electronic device remanufacturing profitable? Why has the company extended its exchange programme by electronic devices? Which electronic devices are being remanufactured at the moment? ▪ What are the obstacles to electronic device take-back and recovery? ▪ Which factors have a significant impact on the pricing structure of electronic components? ▪ In which ways does electronic device remanufacturing complement the aftermarket supply strategy? In which stage of the (new) product lifecycle does electronic device remanufacturing begin? ▪ Who undertakes the warranty adjustment process, the supplier or the VM? Please outline the problem of the rebate reimbursement ▪ Is there a strong competition for electronic cores, similar to the market for engines? Which countermeasures does the company undertake to avoid core diversion to competitors? Who are the main competitors?	▪ Following up issues/questions discovered in Phase Two ▪ Understanding electronic device remanufacturing from an aftermarket management perspective ▪ Aiming to identify the differences and similarities between mechanical and electronic device remanufacturing ▪ Aiming to identify the motives for electronic device remanufacturing ▪ Understanding issues and obstacles within take-back and recovery of electronic devices

Table 25: Specific Line of Enquiry in Research Phase Three (Case Company B; Case Five) – Part 1

Company Description	Questions (Continued)	Key Research Issues
▪ Case Company B ▪ Case Five ▪ Global Warehouse ▪ Interviewees 82 to 111 and 113 to 117 (Appendix F)	▪ Which are the markets for remanufactured electronic devices? Are there any figures about sales in different countries? ▪ What are the main issues and obstacles with regard to the take-back and remanufacturing of electronic devices? ▪ What are the specific operational process steps of electronic device remanufacturing? What are the main issues and obstacles within these processes and how can these be overcome? ▪ Do the suppliers remanufacture for one VM specifically, for several VMs at the same time or also for their own purposes? ▪ Is there a minimum ordering quantity of remanufactured products? If the VM doesn't procure enough remanufactured devices, is this an issue for the supplier? ▪ What are the limitations of electronic device remanufacturing?	▪ Following up issues/questions discovered in Phase Two ▪ Understanding electronic device remanufacturing from an aftermarket management perspective ▪ Aiming to identify the differences and similarities between mechanical and electronic device remanufacturing ▪ Aiming to identify the motives for electronic device remanufacturing ▪ Understanding issues and obstacles within take-back and recovery of electronic devices

Secondary/Archival Data
▪ Internal report: "Supply of Electronic Spare Parts after Phase-Out – A Time Bomb?"
▪ ZVEI report on the long-term supply of electronics spare parts
▪ Internal project report on the development of a track and trace tool for exchange parts/product returns
▪ Internal report on electronics project: take-back and remanufacturing of electronics spare parts and components
▪ Project report: managing the exchange process of parts procured from Supplier D
▪ Prices for a variety of new and remanufactured electronic devices
▪ Process flow map: typical electronic device remanufacturing process
▪ Project report: "Long-term supply of electronic components"
▪ Internal report: Analysis of the product group remanufactured products: overview and issues within the warranty adjustment process

Table 26: Specific Line of Enquiry in Research Phase Three (Case Company B; Case Five) – Part 2

Company Description	Questions	Key Research Issues
▪ Case Company C ▪ Case Six ▪ Electronic Supplier ▪ Interviewee 112 (Appendix F)	▪ Please give a brief outline of the company structure, i.e. number of employees, activities undertaken, position within the group, history etc. ▪ Please outline the main process steps within the electronic device manufacturing process? What are the main obstacles? ▪ Of how many parts does an electronic device consist? How many suppliers provide the parts for the manufacturing of new electronic devices? ▪ What are the main process steps within the remanufacturing process? What are the main issues and obstacles and how may these be overcome? ▪ Why does your company remanufacture electronic devices? What is the motivation behind remanufacturing? ▪ For which companies do you provide remanufacturing services? ▪ What is the company's relationship to Company B? ▪ How is the supplier's activity integrated into the Closed-Loop Supply Chain for electronic devices? How does this supply chain look like? ▪ What impact does product variety have on the remanufacturing process? What impact does it have on inventory levels/stock keeping? ▪ What are the most common sources of product failure? Can an 'as good as new' standard be achieved? ▪ Are new parts added to the process? ▪ What are the remanufacturing volumes per year in total? What are the remanufacturing volumes for Company B? ▪ Is 'design for remanufacturing' considered within new product design? ▪ Who owns the cores that return for remanufacturing: the supplier or the VM?	▪ Following up issues/questions discovered in Phase Two ▪ Understanding electronic device remanufacturing from an operational perspective ▪ Aiming to identify the differences and similarities between mechanical and electronic device remanufacturing ▪ Aiming to identify the motives for electronic device remanufacturing: the supplier's perspective ▪ Understanding issues and obstacles within take-back and recovery of electronic devices ▪ Comparing electronics manufacturing processes with remanufacturing
Secondary/Archival Data		
▪ Process map for operational steps within electronic device remanufacturing		
Process Observation		
▪ Observation of the (new) product manufacturing process of head units ▪ Observation of the remanufacturing process of electronic devices		

Table 27: Specific Line of Enquiry in Research Phase Three (Case Company C; Case Six)

Phase Four: Interview Questions, Key Research Issues and Aims

Research Phase Three was followed by a grounded analysis of the data. However, as already outlined in Section 4.3.2, field visits continue until additional visits only achieve diminishing returns. Phase Four therefore represented the last phase of research, as it was found that additional interviews only provided limited new information. The main aim of Phase Four was the verification of the data gathered on electronic device remanufacturing, but also the generalisation of the overall research results. The first step within this phase was therefore the questionnaire survey undertaken at the ReMaTec trade fair in Amsterdam, The Netherlands. The results are extensively discussed in Chapter Eight.

Case Seven comprised visits to three remanufacturing facilities of Case Company D. The fieldwork was stretched over three days and also involved process mapping of remanufacturing processes as well as the observation of (new) electronic device manufacturing. Similarly to the previous research phases, this field visit aimed at investigating Research Questions 1 to 5 (see Tables 28 and 29), but also sought to validate insights than had been discovered within the first three phases of the research.

This phase of research was concluded by a visit to an independent engine remanufacturer. In the course of the research, it was found that some answers to the research questions may have been specific to the working practices of OEMs. As a result, one of the objectives was to identify whether independent remanufacturing practices and the rationale for independent remanufacturing complied with the findings from the OEM case studies. Table 30 summarises the main questions that were posed within this field visit. It was found that independent working practices differed from OEM remanufacturing. However, as the investigation only included one field visit to one independent remanufacturer, future research needs to further investigate the independent side of the automotive remanufacturing sector.

Company Description	Questions	Key Research Issues
▪ Case Company D ▪ Case Seven ▪ Electronic Supplier ▪ Interviewees 120 to 126 (Appendix F)	▪ Please give a brief outline of the company structure, i.e. number of employees, activities undertaken, position within the group, history etc. ▪ What are the main reasons for the company to engage in the remanufacturing of electronic devices? Why has electronic device remanufacturing begun so late as opposed to the remanufacturing of mechanical components? ▪ More generally, what are the company's motives to establish exchange programmes for remanufactured products? What is the role of environmental regulations, such as the ELV or the WEEE Directives? ▪ Why are VMs so concerned about the supply of semiconductors, an issue which seems to be a problem for the suppliers, not the VM? ▪ Why does remanufacturing play such a significant role within the long-term supply of spare parts? Can the issue of supply be solved/improved through the backwards compatibility of new devices instead? ▪ What exactly is the difference between repair and remanufacturing with regard to electronics? ▪ Which factors determine whether a new product variant is created? How significant are differences between product variants? ▪ Please describe the remanufacturing process for electronic devices. Which devices cannot be remanufactured? ▪ How can an 'as good as new' standard be achieved? Is this possible at all? ▪ Why is there no hybrid manufacturing/remanufacturing plant? Could the two processes be combined? ▪ In the case of complex board management devices that consist of modules produced by different manufacturers: how are these remanufactured? Do competitors have to co-operate? ▪ What are the different types of production errors/returns that your company deals with? What exactly are the differences between 'factory returns', 'zero-mile returns' and 'field returns'? ▪ Is electronic device remanufacturing profitable? What are the decisive factors to a profitable electronic device remanufacturing operation? ▪ Does the company consider 'design for remanufacturing'? Is there an option to focus on 'platform design' in order to decrease product variation within the aftermarket? ▪ Which companies are your main competitors? What are the main players in the market for remanufactured electronic devices?	▪ Clarification and verification of findings from previous research phases ▪ Understanding electronic device remanufacturing from an operational perspective ▪ Further clarification of the differences and similarities between mechanical and electronic device remanufacturing ▪ Aiming to identify the motives for electronic device remanufacturing: the supplier's perspective ▪ Understanding issues and obstacles within take-back and recovery of electronic devices

Table 28: Specific Line of Enquiry in Research Phase Four (Case Company D; Case Seven) – Part 1

Company Description	Questions (Continued)	Key Research Issues
▪ Case Company D ▪ Case Seven ▪ Electronic Supplier ▪ Interviewees 120 to 126 (Appendix F)	▪ In your opinion, will the amount of electronics in cars further increase? What potential impacts could this have on remanufacturing processes and the remanufacturing market? ▪ Is there information feedback to future product design? ▪ Does the rule 'the line comes first' (i.e. the new manufacturing process has priority over new parts) also apply to electronic device remanufacturing? ▪ Are there significantly high inventory levels of cores? Is the problem as distinct as with engines? ▪ Does the VM provide a complete aftermarket range of new products? Are remanufactured devices the only source of spare parts? ▪ Which other aftermarket products are produced by the company? In which market can those products be found? Does the company also supply to auto accessory stores/auto superstores? If yes, in which way are these products different from the OE products? ▪ How long is the warranty for remanufactured parts?	▪ Clarification and verification of findings from previous research phases ▪ Understanding electronic device remanufacturing from an operational perspective ▪ Further clarification of the differences and similarities between mechanical and electronic device remanufacturing ▪ Aiming to identify the motives for electronic device remanufacturing: the supplier's perspective ▪ Understanding issues and obstacles within take-back and recovery of electronic devices

Secondary/Archival Data
▪ Process map for operational steps within electronic device remanufacturing ▪ Process flow maps for different type of product returns: factory returns, zero-mile returns and field returns ▪ Internal company report: "The Chip Industry" ▪ Overview of information and product flows with Company B (Powerpoint Slides)

Process Observation
▪ Observation of the (new) product manufacturing process for a variety of electronic devices ('walking the process') ▪ Observation of the remanufacturing process of electronic devices at three different plants: two owned by Company D, one facility belonging to the subcontractor ('walking the process'; mapping the process

Table 29: Specific Line of Enquiry in Research Phase Four (Case Company D; Case Seven) – Part 2

Company Description	Questions	Key Research Issues
▪ Case Eight ▪ Independent Engine Remanufacturer ▪ Interviewees 134 (Appendix F)	▪ Please give a brief outline of the company structure, i.e. number of employees, activities undertaken, history etc. ▪ Please describe your Closed-Loop Supply Chain: where do cores come from and who are your suppliers for new parts? ▪ Who are the main customers? Garages, wholesalers, distributors? ▪ Please describe the main engine remanufacturing process steps within your facility ▪ What are the lead times for the main process steps? ▪ Do you perceive the increase in electronics as a major issue? ▪ Do you also perform hot and cold tests on the engines? ▪ What are the main issues within the remanufacturing process? ▪ What are the differences between this company's engine remanufacturing activity and the remanufacturing activities undertaken within VM plants? ▪ Please define the different processes: reconditioning, remanufacturing and factory overhaul. Which category would you consider for you engine recovery process? ▪ What are your/your company's main motives to engage in (engine) remanufacturing? ▪ How do you see the future of the engine remanufacturing sector? What do you perceive as the major threats? ▪ Why do engine remanufacturers tend to have very high core and parts inventory levels? Does your company experience the same issues?	▪ Clarification and verification of findings from previous research phases ▪ Intention to generalise findings from case study research by investigating independent engine remanufacturing

Process Observation
▪ Observation of engine remanufacturing process performed by an independent player in the market

Table 30: Specific Line of Enquiry in Research Phase Four (Independent Remanufacturer; Case Eight)

Interview Analysis: Data Triangulation and Pattern Matching

Section 4.2.8 on data analysis has already briefly outlined different ways of analysing interview data. A main distinction was drawn between content analysis, the 'quantification of qualitative data', and grounded analysis, the grouping of data into topics, themes and categories. Within this research grounded analysis was applied. Section 4.3.2 has pointed out that in between the phase of research, data was analysed, as required by the grounded theory method:

> *The grounded theory method stresses discovery and theory development rather than logical deductive reasoning which relies on prior theoretical frameworks. [...]. First, data collection and analysis proceed simultaneously (see Glaser and Strauss 1967). [...]. Grounded theorists shape their data collection from their analytic interpretations and discoveries, and therefore, sharpen their observations. Additionally, they check and fill out emerging ideas by collecting further data.*
>
> (Charmaz, 1983, p.110)

Interview analysis and the interplay between data collection and analysis occurred in the following sequences. Firstly, interviews were conducted (e.g. within the first phase of research). Secondly, interview protocols were transcribed and stored in a database. Thirdly, interview quotes and observations were grouped into categories (grounded analysis). Specific categories were, for example, 'reverse logistics', 'issues within product recovery', 'characteristics of the closed-loop supply chain' and 'motives/rationale for remanufacturing'. In addition, sub-categories emerged. Sub-categories of 'issues within product recovery' were 'inventory/stock management', 'lead times', 'high degree of manual labour' and 'high process lead times'. Fourthly, the specific data from interviews, process observation and secondary data was matched against the literature and theories. It was examined whether the case study observations confirmed, supported or declined findings from previous researchers. New literature was consulted in cases where reviewed literature could not fully explain or cover the case study findings. The new literature was also added to Chapters Two and Three in the thesis. This process was repeated for every further research phase, beginning with the formulation of new questions for investigation. More specifically, the categories of grounded analysis can be found throughout Chapters Six, Seven, Nine and Ten.

With regard to Chapter Six, interview data contained detailed elaboration on reverse logistics processes, product distribution, order flows, the remanufacturing process and obstacles within remanufacturing, amongst others. The working practices of Case Company A (as stored in the interview protocols) were matched against research findings of previous research. This specifically related to findings within product recovery operations (Section 2.3), closed-loop supply chain management (Section 2.4) and remanufacturing (Section 2.5). However, for novel findings or very specific observations, the review of literature could not provide the basis for pattern matching. Examples include the pricing of remanufactured products or case specific observations of obstacles within remanufacturing. For this data, subsequent field visits and further interviews with industry experts were necessary. The same process applied to electronic device remanufacturing. Interview data was grouped into several categories. Chapter Seven reports on categories of characteristics of electronic device remanufacturing, reverse logistics, the remanufacturing process as well as issues and obstacles within remanufacturing, for example. Again, data from interviews, process observation and secondary data was matched against the findings within the literature. However, due to the novelty of electronic device remanufacturing within the sector, the matching against the literature was even more challenging. For certain case specific observations, such as zero-mile returns, literature was rare. On the other hand, interview data on electronic device remanufacturing was matched against the interview data for the more mature process of engine remanufacturing in order to outline differences and similarities between the remanufacturing working practices of both products.

Chapters Nine and Ten contain the results of grounded theory analysis and pattern matching. Chapter Nine outlines the lack of a terminological framework for automotive remanufacturing. In other words, interview data on the understanding of automotive closed-loop supply chains (e.g. reverse logistics, recovery, distribution) supported the establishment of a new terminological framework. The real world closed-loop supply chain models (as developed from interview data) are compared against dominating models that were discussed in the literature review (see Sections 2.2.4 and 9.2.2). It is outlined why the supply chain structures from the literature review could not be applied to the automotive sector. Thereafter, the specific groups and categories of grounded analysis are outlined. Findings from the literature are matched against case study

findings under the appropriate headings. This results in a discussion on the main debates within closed-loop supply chain management. Firstly, case study results are matched against challenges that the literature has proposed for remanufacturing operations. In other words, a pattern taken from the literature is examined with regard to its applicability to the automotive sector. These challenges include reverse logistics and the uncertainty in quantity, quality and timing of returns (see Section 9.3.1). Secondly, new findings from the case study interviews are matched against the main debates in the literature (see Section 9.3.2). Those categories include inventory control as well as recovery planning and control. Under each heading, the categories (as developed from the interview transcripts) are discussed with reference to the specific literature (e.g. Section 2.5.5 with a sub-section on disassembly, recovery planning and control and a separate sub-section on inventory control in a remanufacturing environment).

Chapter Ten also shows categories of topics and themes that were developed from the review of literature (Chapters Two and Three), that emerged from the interviews or during the grounded analysis of the interview data. The first categories refer to the three research questions. Under each heading within Section 10.2, patterns from the theories and from the literature are matched against the 'clusters' of interview data that were developed during analysis. Section 3.2.5 therefore refers to Section 10.2.1 (the ethical or moral motive for remanufacturing). Similarly, Sections 3.4.1 and 3.4.2 relate to Sections 10.2.2 and 10.2.3, respectively. In these cases, detailed interview data (direct quotes) from various interviews is grouped under the appropriate heading. The debate evolves around the comparison between claims within the literature and interview findings. Chapter Ten also reports on categories that have emerged from interviews but were only marginally examined by previous research. This particularly refers to the new motives for automotive remanufacturing that were identified in course of the research. The new motives had not been perceived as relevant in the very early stages of the research. However, the themes became more apparent as they were outlined by an increasing number of interviewees (without previous enquiry or directive) in proceeding stages of the research. As a result, Sections 10.3.1 to 10.3.4 discuss interview categories that emerged from the interviews, but have only been marginally outlined by previous research.

Several additional processes took place alongside this analysis. Firstly, the grounded theory method allowed the researcher to discover aspects that had insufficiently been explored or covered in previous research phases. The interview questions (Tables 17 to 30) showed that the same or similar questions were asked in various research phases in order to clarify or further extend the findings. Secondly, the technique of pattern matching, as defined in Section 4.2.8 was applied as method of analysis. Pattern matching took place with data from different sources, for example by comparing interview data with process observation that was undertaken and secondary data that was obtained during interviews (e.g. company reports; fact sheets; figures). In this way, the data was verified by cross-checking. Thirdly, pattern matching was also applied with regard to theoretical patterns (Chapter Three) or patterns within the literature (Chapter Two). After each phase of research, new and relevant literature was reviewed and added to the dissertation. Through a reflexive approach (see also Section 4.2.8 and Alvesson and Sköldberg, 2000), data was examined with regard to whether it supported, challenged or differed from existing knowledge. As previously outlined, the results of this analysis on the differences and/or similarities between the theoretical realm and the observational (empirical) realm can be found in Chapters Nine and Ten. In particular, Section 9.3, for example, discusses how the empirical observations differed from theoretical research or research undertaken by previous contributors in the field (proposed versus 'real world' challenges).

Figure 11 summarises graphically how data triangulation and pattern matching were applied within this research, with the aims to analyse data, identify gaps, verify findings and making the research more robust.

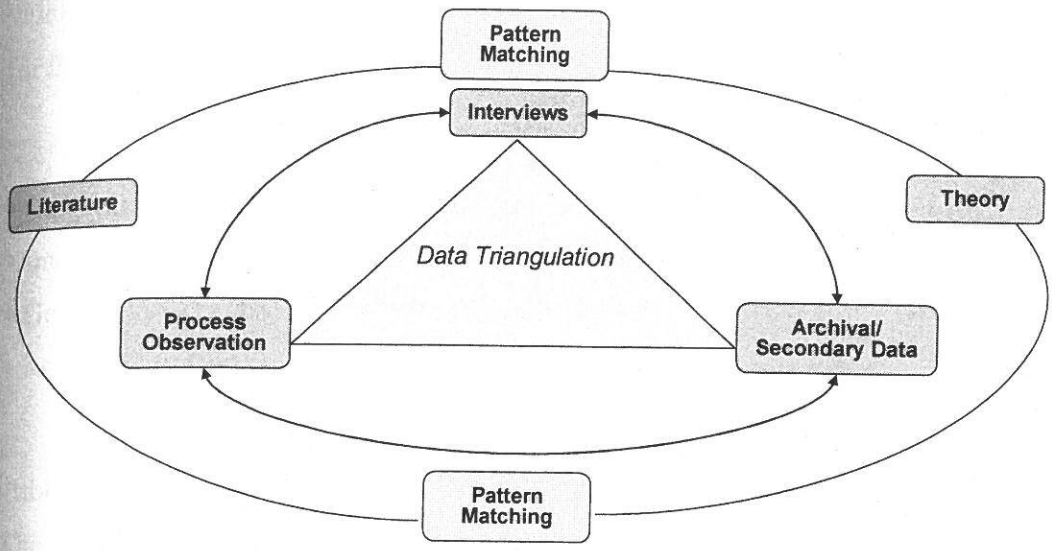


Figure 11: Data Triangulation and Pattern Matching in this Research

4.3.4 Criteria for Judging the Quality of Selected Research Strategy and Methods

As it is the case with any type of research, this research has been undertaken within certain constraints. These limitations include aspects, such as restricted access to case companies, limited financial means, as well as time restrictions for the completion of the thesis. This section however, judges the quality of the case study research strategy and the data collection methods. The weaknesses of case study research, interviewing and the questionnaire survey have been previously outlined. At this point, the author explains how these weaknesses have been addressed, in order to increase the overall quality, validity and robustness of this research. However, it has to be noted that any empirical research in business management incorporates a certain degree of 'contingency'. The research may therefore be well planned, but the involvement of people increases uncertainty. Lambert *et al.* (1998b) confirm the crucial impact of people and culture, for example.

The Case Study Strategy

The concept of validity has been briefly discussed in the section on case study strategies. This section is concerned with the overall validity of the research. As previously outlined, validity includes construct validity, internal validity, external

validity (generalisability) (Emory, 1980; Yin, 2003). The main research 'design tests' for this research are:

- Construct validity (ensuring that the appropriate measures were applied)
- Internal validity (establishment of a causal relationship)
- Generalisability (how findings can be generalised)
- Replicability (the research can be repeated with the same results)

Tables 17 and 18 demonstrate how design tests have been applied within this research. The tactics applied have been drawn from Yin (1989, 1994) and Robson (2002).

Test	Tactics	Phase of Research	Application within this Research
Construct Validity	Use of multiple sources of evidence (Yin, 1989, 1994)	Data collection	▪ Use of eight different cases ▪ Sources included a range of market players, e.g. VMs, suppliers and independents ▪ Use of secondary data, company reports and presentations ▪ Multiple data collection methods (interviews; survey; 'walking the process') ▪ Application of methods in various ways (e.g. semi- and unstructured interviews) ▪ Re-interviewing the same respondents (see list of interviews; Appendix F) ▪ Interviewing different respondents about similar or identical aspects
	Have key informants review draft case study report (Yin, 1989, 1994)	Data collection	▪ Data examined by PhD supervisors (feedback) ▪ Follow-up interviews with industry experts ▪ Dissemination of research ideas and findings to trade journals and remanufacturing experts (feedback)
	Pattern matching (Trochim, 2002b)	Data collection	▪ Continuous comparison between initial research findings and previous research by others ▪ Pattern matching in between cases ▪ Pattern matching in between product groups
	Establish a chain of evidence (Yin1989, 1994)	Composition	▪ Gradual development of four different research phases ▪ Using own findings and evidence from previous research to refine the overall line of enquiry ▪ Following the line of enquiry from research questions to specific evidence and results, as proposed by Yin (2003)

Table 31: Application of Case Study Tactics to Ensure the Quality of the Research – Part 1

Test	Tactics	Phase of Research	Application within this Research
Internal Validity	Pattern matching (Yin, 2003)	Data analysis	▪ See Table 31
	Do explanation-building (Yin, 2003)	Data analysis	▪ Explanations of phenomena during the research due to 'grounded theory' ▪ Academic journal publications; reviewers' feedback (e.g. Seitz and Peattie, 2004) ▪ Conference publications and presentations for feedback
	Prolonged engagement in research (Lincoln, 1985)	Data analysis	▪ Sufficient time was invested to understand the 'basics', e.g. engine teardown training and in-depth process observation ▪ Fieldwork took place over 19 months ▪ In-depth research included two case studies in which the author stayed at the facilities for four weeks each
Generalisability	Use replication logic in multiple-case studies (Yin 1994, 2003)	Research design	▪ Aim to replicate findings of one case in others (e.g. various visits to engine plants) ▪ In the case of contradictory findings, initial propositions were refined (see four different phases of research) and tested in further cases ▪ Highlighting of differences and similarities among cases, products and players
Reliability	Use case study protocol (Yin, 2003)	Data collection	▪ Documentation of procedures within each case ▪ Documentation of each interview (see list of interviews)
	Develop case study database (Yin, 2003)	Data collection	▪ Establishment of Case Company database ▪ Appropriate storage of case study notes, such as interview results or company documents

Table 32: Application of Case Study Tactics to Ensure the Quality of the Research – Part 2

Data Collection Methods

The application of different data collection methods, the so-called 'methodological triangulation' or 'triangulation of measurement' (Webb *et al.*, 1966), increases the degree of generalisability of research findings. Within this research, the data was mainly collected through interviewing, by a questionnaire survey and by process observation ('walking the process'). Moreover, secondary data was gathered. This section, however, only demonstrates how the weaknesses of the main data collection methods were addressed.

As outlined earlier, face-to-face interviewing has often been criticised as being at a strong risk of bias, due to the interaction between the interviewee and interviewer. "However, there is a very real concern about interviewers imposing their own reference frame on interviewees, both when questions are asked and when answers are interpreted" (Easterby-Smith *et al.*, 2002, p.93). This is particularly true for this research, since a large amount of the data collection was undertaken in Germany, where questions were posed in German, but interviews were transcribed in both languages and results and findings were translated into English. According to Easterby-Smith *et al.* (2002), countermeasures, such as open questions, probing and reflecting of what has been said, may help to limit interview bias. During the fieldwork, interviews were initially of an unstructured nature and gradually became more structured. Bias was avoided by re-interviewing respondents, interviewing different respondents about identical aspects, as well as enquiring identical issues within various cases or locations (see list of interviews; Appendix F). The motives behind engine remanufacturing, for example, were investigated at Company A's Headquarters, the Global Warehouse and the Used Parts Centre. In this way, the main findings could be reviewed, confirmed, but also rated with regard to their importance. This also increased the likelihood of eliminating administrative errors, which could have easily occurred in a busy, noisy and dirty setting, such as a remanufacturing plant. By verifying results at further interview settings, this type of bias was decreased.

Further bias may occur due to the interviewer's appearance. Being a female interviewer in a male-dominated environment, as for example within the investigation of processes on the engine remanufacturing shop floor, may cause bias within the responses. The author often experienced a certain reservation by male respondents. Many of them thought that a female researcher may have limited knowledge with regard to the technical understanding of products and processes, which resulted in them elaborating on very basic concepts. In one case, in which the interviewer visited a remanufacturing facility with a male colleague, one of the employees did not face the author, when she asked questions. Instead, he replied to the male colleague, even though the author had asked the question. Concluding, the author may have not had access to the full spectrum of respondent's beliefs and ideas, due to the fact that these thought a female researcher could not have the same technical knowledge compared to a male researcher. It has to be said that the difficult situation noted above occurred in a shop-floor environment. The author never experienced any obstacles in interviews with respondents from the upper management. Within other remanufacturing facilities, however, these situations could be avoided by probing in a way that demonstrated the technical knowledge of the interviewer.

With regard to the questionnaire survey, criticism has been expressed by Silverman (1985), who explains that questionnaires are often disadvantaged with regard to the limited understanding they provide. However, since the questionnaire was undertaken alongside in-depth case studies, this concern was eliminated. Oppenheim (1992) and Zikmund (1994) note the impact of non-respondents in mail surveys, for example. Since questionnaire surveys are generally characterised by low response rates (Oppenheim, 1992), a bias may occur among those that responded to the questionnaire.

> *The issue here concerns not the number or proportion of non-respondents, but the possibility of bias. We need to find out whether the reasons for the non-response are somehow connected with the topic of our research; for example, in a general study of attitudes to unemployment, have many of the unemployed in our sample been unwilling to respond? In other words, is there a confounding bias?*
>
> (Oppenheim, 1992, p.106)

The questionnaire was administered by the author and all exhibitors that were approached at the trade fair were willing to participate in the survey. Yet, the response rate was still influenced by the author who undertook the survey single-handed. The overall response rate may be described as 26.7%, since 48 among 180 exhibitors were surveyed within three days. Although additional researchers could have interviewed the remaining exhibitors and thereby increased the overall response rate, the advantage of this procedure was the fact, that the author was present in order to clarify issues regarding the wording of questions, for example. Therefore, response-bias was eliminated to a certain degree. The questionnaire survey was conducted in English, however, many of the respondents were not from an Anglophone background, which could have led to misunderstandings due to the translation process by respondents.

Sampling bias was excluded due to the fact that random sampling had been replaced by 'self-selection', which included the trade fair's exhibitors as a sample of the whole population. The author therefore had no influence on the questionnaire sample.[17]

However, this questionnaire survey does not claim to be all-embracing nor complete, but in combination with the previous research, it sought to provide data and methodological triangulation. Oppenheim (1992) argues that advantages and disadvantages of the questionnaire survey are almost a mirror-image of the interview's advantages and disadvantages, hence, the author felt that Oppenheim (1992) confirms and approves the combination of interviews and a questionnaire survey for data collection, since the advantages of one data collection method balance the disadvantages of the second method.

[17] It was furthermore assumed that the data collected at the trade fair would be of a high quality, since very recent trends were discussed among practitioners. Moreover, exhibiting companies were expected to demonstrate best business practice, since they had shown interest in the trade fair. Managing directors and their employees took part in seminars and workshops which were organised by the remanufacturing associations. Furthermore, most responding companies were members of at least one remanufacturing association. Accompanying industry material, such as company information, descriptions of products and processes as well as catalogues have been additionally obtained, in order to complement the research.

Methodological Contribution to Remanufacturing Research

Tables 19 and 20 display the methodological approaches recent key research in the area of remanufacturing has taken. They demonstrate that few contributors have taken a holistic point of view (e.g. Steinhilper, 1998, Guide and Van Wassenhove, 2003c), but many have focused on one aspect of remanufacturing, as already outlined in Chapter Two. Most large-scale surveys have taken an American perspective.[18]

Consequently, this research seeks to provide a methodological contribution by the selection of research strategy, data collection methods, participants and a perspective, which has not been undertaken in this combination before. The research hereby aims to increase its novelty as well as its quality. Chapter Eleven will further outline and summarise the methodological contribution made by this thesis.

[18] For an American perspective, please refer to Lund (1996), Hammond *et al.* (1998) and Hauser and Lund (2003).

Author (s)	Approach/Strategy	Methods	Types of Data	Participant(s)	Perspective	Product(s)
Ferrer (1997b)	▪ Not specified	▪ Mathematical modelling	▪ Quantitative	▪ Not specified	▪ Academic ▪ Remanufacturing process	▪ Tyres
Guide and Van Wassenhove (2003c)	▪ Case study ▪ Secondary data	▪ Not specified	▪ Not specified	▪ Recovery companies	▪ Academic ▪ Whole CLSC ▪ Multiple cases	▪ Photocopiers ▪ Tyres ▪ Toner cartridges ▪ Single use cameras ▪ Cellular telephones
Guide (2000)	▪ Survey	▪ Questionnaire	▪ Quantitative	▪ Remanufacturing companies	▪ Academic ▪ Remanufacturing process	▪ Automotive ▪ Aerospace ▪ Machinery ▪ Office equipment ▪ Other small items
Hammond et al. (1998)	▪ Survey	▪ Questionnaire	▪ Quantitative ▪ Qualitative	▪ Remanufacturing companies	▪ Academic ▪ Remanufacturing process	▪ Automotive
Hauser and Lund (2003)	▪ Survey	▪ Questionnaire	▪ Quantitative	▪ Remanufacturing companies	▪ Academic ▪ Broad industry overview ▪ No SC focus ▪ No logistics focus	▪ Automotive ▪ Compressors ▪ Electrical apparatus ▪ Machinery ▪ Office furniture ▪ Toner cartridges ▪ Valves ▪ Other

Table 33: Methodological Approaches applied by Previous Research on Remanufacturing – Part 1

Author (s)	Approach/Strategy	Methods	Types of Data	Participant(s)	Perspective	Product(s)
Johannes (1996)	▪ Case study	▪ Not specified	▪ Quantitative ▪ Qualitative	▪ Remanufacturing company	▪ Academic ▪ Recovery process ▪ Logistics focus ▪ Single case	▪ Automotive
Krikke et al. (2003)	▪ Case study ▪ Secondary data	▪ Mathematical modelling	▪ Quantitative	▪ Remanufacturing company	▪ Academic ▪ CLSC ▪ Logistics ▪ Single case	▪ Refrigerators
Langella (2003)	▪ Case study	▪ Mathematical modelling ▪ Numerical examples	▪ Quantitative	▪ Remanufacturing company	▪ Academic ▪ Disassembly planning ▪ No SC focus ▪ Single case	▪ Automotive
Steinhilper (1998)	▪ Not specified	▪ Not specified	▪ Overall industry data	▪ Remanufacturing companies	▪ Practitioner ▪ In-depth ▪ No SC focus ▪ No logistics focus ▪ Broad industry overview	▪ Automotive ▪ Machine tools ▪ Industrial robots ▪ Copying machines ▪ Electronic products ▪ Office furniture
Van der Laan (1997)	▪ Case study	▪ Mathematical modelling ▪ Simulation	▪ Quantitative	▪ Remanufacturing company	▪ Academic ▪ Inventory control ▪ No SC focus ▪ Single case	▪ Automotive

Table 34: Methodological Approaches applied by Previous Research on Remanufacturing – Part 2

4.4 Conclusion

Chapter Three has outlined and discussed the lack of an appropriate theoretical framework for research within closed-loop supply chain management. This chapter has therefore provided the link between the research needs, which were identified in Chapters Two and Three and the data collection. This link was established by selecting a grounded theory approach for this research. With regard to the aim of discovering theory, rather than verifying theory, the research design has been based on the requirements of the theory-building process.

The second consideration concerning the selection of data collection methods was the effectiveness with which the data collection methods could answer the research questions. Therefore, the case study strategy and the data collection methods of interviewing, questionnaire and process observation ('walking the process') were selected.

Chapter Four has also presented and justified the delineations of the research. Due to a combination of grounded theory, inductive thinking and exploratory research, the direction of the research has been formed, developed and shifted throughout the research process. The overall line of enquiry, the changes of direction that occurred, as well as the reasons for these changes have been extensively discussed. In addition, the chapter has extensively discussed the questions that were posed during interviews, the distribution of interviews and interview questions at different research phases and the main key issues covered within interviews. Moreover, the interview structure and process were outlined and it was explained how the interview data was analysed. The chapter has concluded by justifying how the overall quality of the research was ensured.

The subsequent Chapter Five represents an introduction to the automotive supply chain, the aftermarket as well as the remanufacturing sector. It therefore provides the industrial framework for this dissertation.

Chapter Five
The Automotive Supply Chain and the Aftermarket

5.1 Introduction

This chapter's purpose is to portray and illustrate the key characteristics of the automotive supply chain and the automotive aftermarket. The understanding of the automotive aftermarket is essential to this research, since this is the market in which remanufactured products are distributed. However, academic research has only marginally investigated the automotive aftermarket. For this reason, a considerable amount of this chapter is based on industry reports and publications in trade journals. Moreover, the chapter comprises background research, such as data from interviews with first tier suppliers, original equipment producers and various industry experts.

Furthermore, the chapter gives an overview of the European remanufacturing sector and current trends within the industry, such as the increasing interest in electronic device remanufacturing. As Chapter Four has demonstrated, this trend was discovered within the research and has shaped the dissertation. Hence, the chapter also differentiates between the two product groups, engines and electronics. This discussion provides a basis for the subsequent, empirical chapters.

Overall, the chapter takes a global view on production and manufacturing aspects, since the automotive supply chain may not be limited to a certain country or continent. However, with regard to the aftermarket, this chapter seeks to narrow down the scope of the analysis and is therefore based on a European perspective. The main reason for this limitation is the fact that, as opposed to the global automotive supply chain, the market for replacement and spare parts is very country-specific. Particular reference will be made to the German market, since most of the research was conducted in that country.

5.2 Automotive Supply Chain

A car consists of approximately 15,000 parts and accessories (Brunnermeier and Martin, 1999), whereof the vehicle manufacturer produces only some. Due to that, there are an uncountable number of players involved in the process of manufacturing a car. Participating companies are located in different countries, vary in size and may be involved in supply chains of other industries. Hence, it is challenging to identify a single automotive supply chain. This section, however, strives to give an overview of the current state of the automotive supply chain.

5.2.1 Structure and Characteristics

The current automotive supply chain is characterised by a concentration of a few vehicle manufacturers and a multitude of direct and sub-tier suppliers. There is strong competition among vehicle manufacturers. However, in the downstream segments of the supply chain (suppliers), the industry is less concentrated and therefore more competitive (Brunnermeier and Martin, 1999). There are hundreds of first tier suppliers (some large, some small), and thousands of sub-tier suppliers, mostly small (Brunnermeier and Martin, 1999). Mergers and acquisitions have reduced the number of vehicle manufacturers to eleven (Nieuwenhuis and Wells, 2003). It is expected, that this trend will continue and will also affect first-tier and sub-tier suppliers. PriceWaterhouseCoopers (no date given) assume that by 2010, the number of first-tier suppliers will be reduced globally from around 800 today, to 35, and the number of sub-tier companies will be reduced from approximately 10,000 to 800.

The observed reduction of players (vehicle manufacturers) in the industry is also taking place within the supply base. The consolidation of suppliers to form 'mega suppliers' is raising concern among vehicle manufacturers, particularly if a specific mega supplier becomes the only source of a component (Flynn *et al.*, 2001). Due to the fierce competition in the supply base and the plenitude of choice for VMs, the 'traditional' distribution of power lays within the hands of the vehicle manufacturer. With more responsibility for suppliers, there may be a shift within the power structure of the automotive supply chain. These changes have an impact on the supplier selection process by vehicle manufacturers.

> *Today, virtually no automotive executive would report that price is the sole criterion considered when making a sourcing decision. Instead, price is but one – albeit and especially important one – of a number of factors, including quality, design, capability, part durability, and reliability, that manufacturers use to identify and evaluate potential suppliers.*
>
> (Flynn *et al.*, 2001, p.1)

Overall, the automotive supply chain is very complex, a factor, which is largely caused by the large number of materials in a car (Deutz, no date given). A further determining factor for complexity is the fact that vehicle manufacturers tend to buy ready-made components, from the first tier suppliers. However, these suppliers themselves are often multinational corporations. It is expected that this so-called 'modular manufacturing', where the final vehicle assembly mainly consists of putting together these ready-made modules, will increase in near future (Nieuwenhuis and Wells, 2002). The term 'vehicle manufacturer' is therefore confusing, since automakers nowadays manufacture just 23% of the parts which are either built into a vehicle or sold on the aftermarket (CSC Ploenzke AG, 2001). Hence, car manufacturers are shifting away from 'vehicle manufacturing' in the true sense of the word, towards being 'vehicle assemblers' (Flynn *et al.*, 1996; Strategis, 1999).

Despite the vehicle manufacturers' strong dependency on suppliers, supplying companies do not seem to hold a strong bargaining position. Competition among suppliers is fierce due to a decrease of car sales in the past years. Therefore, automobile

manufacturers force suppliers to reduce their prices for components, assemblies and modules, in order to stay competitive (Magna, 2002). In addition, suppliers need to show initiative and flexibility, as seen in the production plant of the 'Smart' in Hambach (France), where suppliers directly located their component plants next to the vehicle assembly plant, in order to achieve a minimum of logistics effort and a just-in-time delivery. Current trends show that the automotive supply chain is shifting away from its historical structure of vehicle manufacturers, first tier and sub-tier suppliers. A rather mixed and indistinct picture of this industry's supply chain has emerged. It seems, as if supplying companies may not be solely declared as direct or sub-tier suppliers. According to Flynn *et al.* (1996) there is a variety of supplier models, often combined, depending on the proximity between supplier and vehicle manufacturer or type of the product. Supplier models may be classified into three categories. A supplier may be a system integrator, which indicates that the supplying corporation engineers and supplies modules or systems of parts and components. The second type of supplier (direct or first tier) manufactures parts and components, which are directly delivered to the vehicle assembly. The last category comprises companies which supply products for the first two categories, hence, they only supply indirectly to the vehicle manufacturer. However, since some companies may fall into more than one category, a particular generalisation with regard to one players' place in the supply chain can no longer be made.

5.2.2 Vehicle Manufacturer - Supplier Relationship

Flynn *et al.* (2001) conducted a study on vehicle manufacturer-supplier relationships within the North American automotive industry. One of the major findings revealed that more and more responsibility is transferred from the vehicle manufacturers to their suppliers. Today, system integrators and direct suppliers often carry out activities which have been traditionally performed by automobile manufacturers (Magna, 2002). This includes the involvement of direct suppliers at early stages in the design, development and engineering of components and systems (Womack *et al.*, 1990; Womack and Jones, 1996). Hence, more responsibility is given to the suppliers. In contrast, suppliers experience increasing cost reduction pressure at growing design and engineering responsibility. However, in return, supplying companies expect long-term contracts, an

aspect, which has developed into key criteria among suppliers with regard to their customer selection process (Flynn *et al.*, 2001). According to Flynn *et al.* (2001), there are three styles of manufacturer-supplier partnerships. Firstly, the Japanese-style, which is characterised by mutual commitment and a long-term contract with the aim to optimise the whole supply chain. Compared to this model, supplier relationships in the United States tend to be of short-term nature with a lack of customer commitment, as perceived by the suppliers. Europeans seem to be located in between these models with elements of both. Overall, suppliers, who take on responsibility for vehicle manufacturers, often develop a strong partnership with their customers, rather than a relationship only. However, vehicle manufacturers seem to neglect that the assignment of more responsibility to the supply base involves loss of control and authority over parts and components. This is particularly relevant to parts and components, which are completely procured from outside, such as entertainment electronics (e.g. radios, CD-players). In this case, suppliers will prevail with regard to product documentation, manufacturing and even represent the only source for the supply of spare and replacement parts for the aftermarket.

5.3 The Automotive Aftermarket

The market, that provides automotive products and services for vehicles which have been sold, the so-called 'automotive aftermarket', is hard-fought (CSC Ploenzke AG, 2001). According to Chieux and Kiff (1999), the term 'after-sales' comprises all operations involved in servicing and repairing a vehicle, excluding body repairs. Hence, the 'aftermarket' is defined as "the market for parts and accessories used in the upkeep or enhancement of a previous purchase, as of a car or computer" (Online Dictionary, 2002). This market is divided into two parts, the warranty service segment and the non-warranty service, with an estimated proportion of 1:20. Overall, the after sales business is seen as main profit driver, since dealers' gross profit consists of 20% spare parts and 30% service labour (SAP AG, 2000).

5.3.1 Aftermarket Structure and Players

The automotive aftermarket is in constant change: increasing demand from customers at decreasing loyalty with regard to brand and manufacturer. In addition to product characteristics and price, the service aspect is gaining importance. According to CSC Ploenzke AG (2001), more than 50% of the turnover in the European automotive market is generated in the aftermarket. The aftermarket is a major source of profit for vehicle manufacturers and their franchised dealers. In contrast, at the retail end of the new car business, especially at the lower end of the market (mass market), margins are very thin. This has been particularly highlighted by Hill (2002), who states that as opposed to new car sales, the aftermarket is healthy and highly competitive. However, the continuously improving quality of cars has lead to a decrease in after-sales (Kiff and Chieux, 1998). In the past, this decrease was offset by a growth in the vehicle park. Chieux and Kiff (1999) claim that "for mature markets this is no longer true and the value of after sales is being sustained only by increases in the price of parts and particularly of labour" (p.3). McIvor *et al.* (1998) further add that particularly the European car market has become so saturated that the only demand left is that on a replacement basis. As a result, players in the aftermarket focus on older cars and face another challenge. Owner of older cars might not be willing to invest larger sums in repairs. Kiff and Chieux (1998) argue that "[...] it should be remembered that if an older car, of relatively low value, requires a costly repair to a sub-system (rather than a simple repair to a component as - in the past) the cost of such a repair will increase the likelihood of scrappage [...]" (p.24). This is particular true for cars, which have been involved in accidents. A determining factor hereby is the rising of body shop repair prices and the growing fitment of airbags.

Kiff and Chieux (1998) add that their above statements need further evaluation. However, initial research indicated that customers tend to consider repair for critical systems. Regarding any other minor repairs, the customers use the car without the benefit of certain features (Kiff and Chieux, 1998). These findings have to be included in this research. As noted by Wells and Nieuwenhuis (2001), a car engine is a very expensive aggregate. However, this is also true for remanufactured engines. Generally, the remanufacturing industry emphasises the price advantage of its remanufactured

parts. However, remanufactured products are sold between 40% and 80% of a new product price (Steinhilper, 1998), which may represent a costly investment for owners of older cars.

The vehicle manufacturer's influence on the aftermarket business is less than the influence on new car sales. One of the main reasons is the extension of service intervals and improved vehicle quality. According to the SAP AG (2000), light car maintenance after the cover period (1-2 years) is often transferred from the franchised dealers system to the (independent) maintenance market, such as fast-fit chains. In addition, the second owner of a car (after an average car's age of 4 years), rather consults the independent maintenance providers, even for extensive repair. Hence, franchised dealers in this market have a share of less than 50% (SAP AG, 2000).

> *There is fierce competition between brand franchised dealers and fast fit chains. The latter act more aggressively and win new customers with lower, fixed prices and fast services. They concentrate on standard work. Parts do not always meet the quality standards required by manufacturers. In addition, franchised automobile dealership site selection is optimized for new car retailing, not for aftersales service.*
>
> (SAP AG, 2000, p.43)

Original manufacturers therefore try to counterbalance this deficit by introducing 'no-wait-repairs' and lower prices for wear and tear parts, since the once unique position of car dealers with regard to car repairs (servicing) and the sale of accessories has been threatened by other players in the market. Fast-fit chains, auto centres, hypermarkets, as well as groups of specialised wholesalers have thrust themselves into the market for replacements, servicing and accessories (Lewis, G, 1991; Hammant *et al.*, 1999). Vehicle manufacturers and larger parts suppliers have responded to this threat by copying retailing concepts, such as the fast-fit idea. The first followers were Ford with Rapid Fit and Vauxhall's MasterFit in the beginning of the 1990s (Way, 2003). Today, there is also Renault-Minute, Peugeot Service Immediat and from the supplier side, Bosch Service, for example.

The European aftermarket consists of four levels: manufacturing, wholesale, service and repair, as well as the consumer. The aftermarket share is still 63% for the franchised dealer system (CSC Ploenzke AG, 2001). Other sources claim that overall, half of the European Aftermarket is in the hands of independent repairers and distributors. However, figures are very country-specific. In Germany, for example, around 30% of the aftermarket demand is said to be satisfied by independents, compared to 70% in the UK (Anonymous, no date given). Overall, Germany is seen as a highly sophisticated market in which prompt after sales service and technical support are significant requirements (Strategis, 1999). As shown in Figure 12, vehicle manufacturers use their own distribution networks.

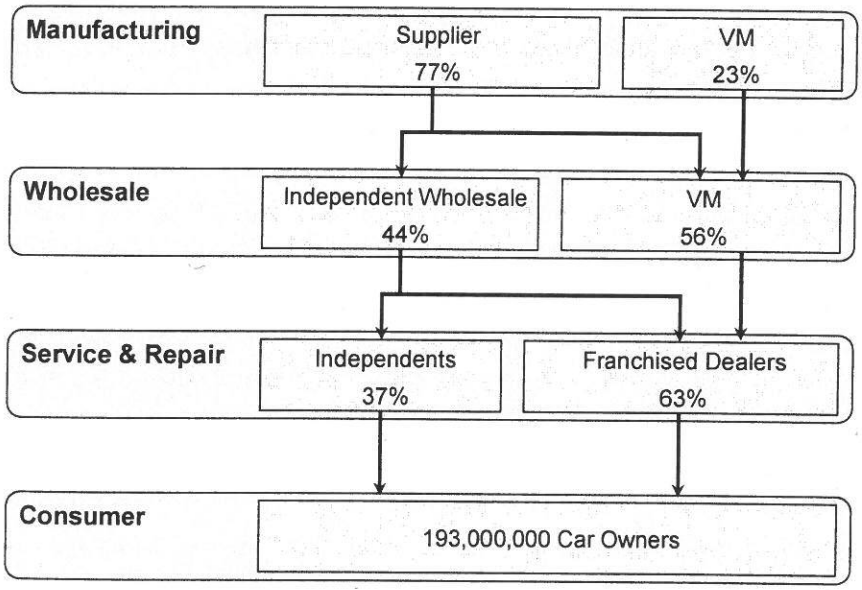


Figure 12: The Four Levels of the European Aftermarket
(Source: reproduced from CSC Ploenzke AG, 2001, p.4; translated from German)

5.3.2 Aftermarket Distribution Structure – An Example

This section discusses the specific aftermarket distribution structure, taking the example of wiper blades (see Figure 13). The products may follow three major routes to reach the end-user (car owner). The original equipment (OE) wiper blade supplier produces wiper blades for the vehicle assembly plant. In these cases, the vehicle manufacturer's trademark can be found on the product. Apart from that, the wiper blade manufacturer also produces the aftermarket range for the VM. Those products are generally identical to the ones, which have initially been built into the car. However, depending on the agreement between supplier and vehicle manufacturer, these products may show the VM's brand, or both the VM's and the supplier's brand. The wiper blade manufacturer delivers the VM's aftermarket products to its Global Warehouse, from which they are distributed to a national warehouse. In some European countries, products are delivered from the vehicle manufacturer's Global Warehouse directly to franchised dealers and subsidiaries. However, the general route follows via a national distribution centre. The new European Block Exemption Regulation now allows independent garages to purchase original spare and replacement parts (OES) from the VM, as long as these garages meet certain quality standards and are authorised by the VM.[19] However, before this regulation came into force, the OES products were distributed through the network of franchised dealers and subsidiaries. From there, Figure 13 shows arrows to the self-repairer and hobbyists, but in case of franchised dealers, subsidiaries and independent garages, the wiper blades will be, in most cases, exchanged at the retail level.

[19] One of the most recent interferences into parts distribution has been the new so-called 'Block Exemption Regulation' (CEC, 2002a). The regulation of 1995 has exempt vehicle manufacturers from the provisions of the Treaty of Rome, which prohibits vertical restrictive practices in trading. Without the exemption, the Selective and Exclusive Distribution (SED) system performed by vehicle manufacturers through their exclusive distribution networks is considered as a restrictive trading agreement. The motor industry, however, argues that this exclusive distribution network ensures professional maintenance for an industry sector in which safety plays a major role, particularly within product use. The new regulation, which came into force in October 2002, moves the balance of power. Dealers are now allowed to represent more than one brand, presuming they physically separate the products (Verband der Automobilindustrie, 2003).

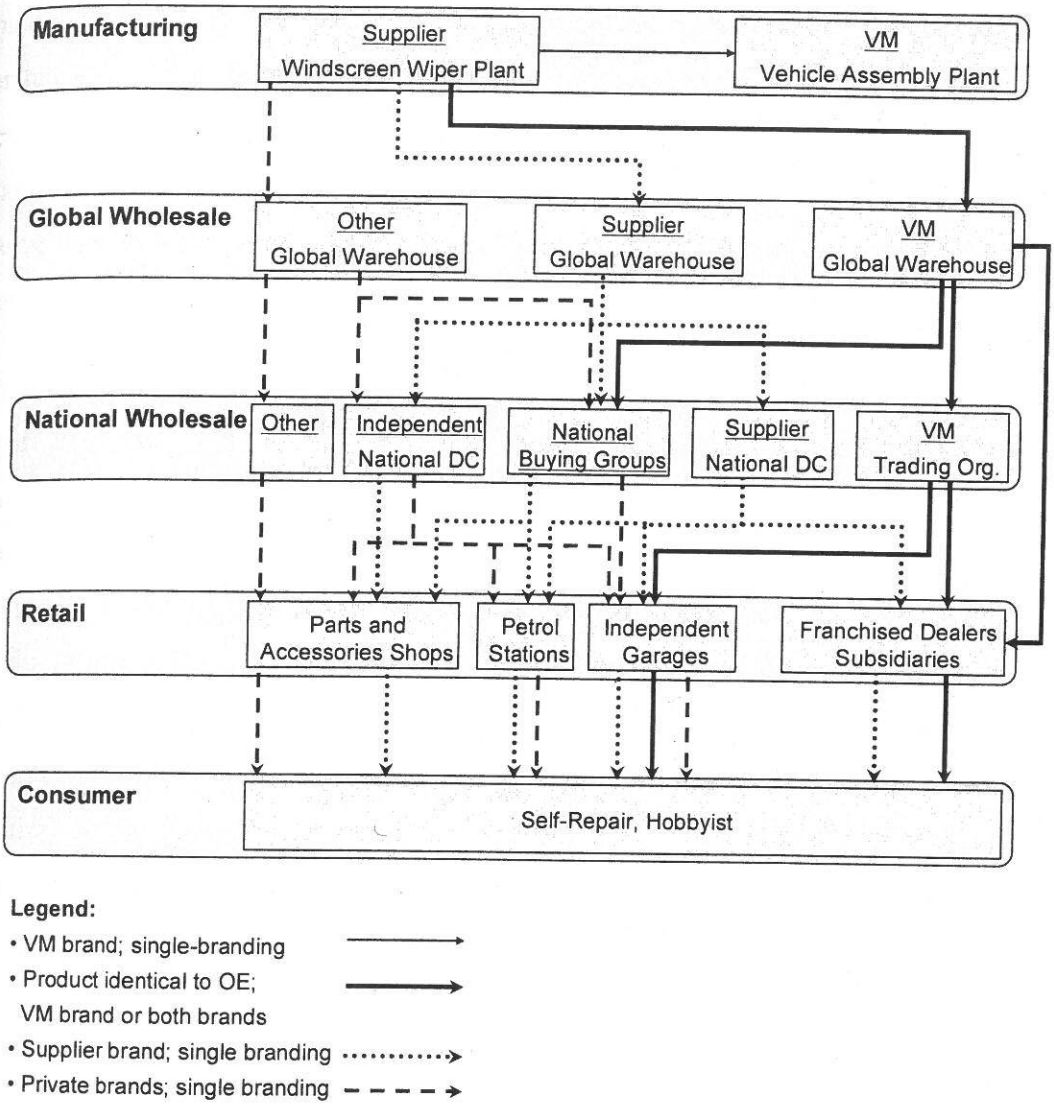


Figure 13: Routes to the German Aftermarket: The Example of Wiper Blades (Source: interview with the Marketing Manager of a first tier supplier)

Some low volume replacement parts are solely available through the 'VM route'. This mainly concerns parts for which there is no interest from the independents to provide these in the product range. Hence, a vehicle manufacturer is obliged to provide any spare part, even parts with negative profits. On the other hand, the independent parts manufacturer can be selective and will settle for high-demand replacement parts. Original equipment suppliers, such as Bosch, Valeo or Magneti Marelli, also manufacture replacement parts within their own brands. Since in this case, too, the car brand is not associated with the aftermarket performance (e.g. parts availability), these companies can be selective in their aftermarket production programme. To ensure

customer protection, European law obliges vehicle manufacturers to provide spare parts for ten years after the phase-out of a particular car model (BMW Info Service, 2003). Several car producers have voluntarily extended this period in order to support their luxury brands and satisfy customers. However, if a particular part is solely available via the vehicle manufacturer's distribution system, independent garages have to procure this part from the vehicle manufacturers trading organisation.

Apart from the OES product range, the supplier may have its own aftermarket brand. These products follow a similar distribution pattern via a global and a national warehouse, both owned by the supplier. However, this brand of wiper blades may also be sold to independent parts wholesales (distributors), dealing with a variety of products. From there, the spare parts are generally purchased by independent garages and parts and accessory shops (e.g. Halfords in the UK or Auto-Teile-Unger in Germany). The consumer (car user), may therefore buy these directly from a parts retailer, or the independent garage installs the product. In the case of self-repair, the consumer usually undertakes 'easier' replacements himself and may consult another person for an 'informal fitting' in the case of major repairs.

The third major route to the aftermarket also begins in the wiper-blade manufacturing plant. There is a large amount of 'independent brands' in the market. Some of these may be 'private brands' from distributors, such as parts and accessory shops. The wiper-blade manufacturer produces these for distribution in the independent channel, mainly via the parts shops. Figure 13 visualises these routes as explained. However, there may be bypasses and exceptions to these three 'general routes', which are not discussed at this place.

Following this discussion, a differentiation has to be made with regard to car parts (as shown in Table 35). On the one hand, there are parts which are destined to be built into new cars in the vehicle assembly plant, the so-called 'original equipment' (OEM part). On the other hand, there are parts which are manufactured for the aftermarket. OEM parts may originate from two different sources, such as the vehicle manufacturer or the

supplier. The same is true for replacement and spare parts (original spare parts; OES parts) produced by the either the vehicle manufacturer or the supplier. Table 35 outlines the different sources of parts and the markets in which they operate.

Type	Source/Manufacturer	Use
Original Equipment	▪ Vehicle manufacturer ▪ Supplier	▪ Vehicle assembly / production
Original Part	▪ Vehicle manufacturer ▪ Supplier	▪ Vehicle assembly / production ▪ Aftermarket (franchised)
Original Spare Part	▪ Vehicle manufacturer ▪ Supplier	▪ Aftermarket (franchised)
Non-Original Part	▪ Supplier ▪ Supplier's brand or other well-known brand	▪ Aftermarket (independent)
Identical Part	▪ Supplier ▪ VM's brand or supplier's brand	▪ Aftermarket (independent)
Non-Identical Part	▪ Supplier	▪ Aftermarket (independent)

Table 35: Car Part Manufacturers and Markets
(Source: summary of CSC Ploenzke AG, 2001)

5.3.3 Spare Parts Management

This section is based on information obtained alongside the case study research which is presented in Chapters Six and Seven. It refers to one specific vehicle manufacturer, but is assumed to be valid for other vehicle manufacturers.

According to interviewees at Company A, the automotive aftermarket used to be structured in a very specific way. The 'classic segmentation' of the aftermarket included the VM, who supplied the market with spare parts from a car model's introduction to approximately year four. From year four to year eight, the suppliers provided spare parts to customers. However, this 'classic division' of the aftermarket has loosened and does not exist as such any longer.

Legislation demands a 10-year period of supply of spare and replacement parts after production phase-out by vehicle manufacturers (BMW Info Service, 2003). As noted

before, vehicle manufacturers provide any kind of spare parts, even low volume replacements. Consequently, with growing car model choices for customers, 'facelifts' and at least ten years of covering-period, vehicle manufacturers are facing serious issues within the management of spare and replacement parts. Background research has revealed that between 2,500 and 6,000 new part numbers are introduced with every new passenger car. Other sources claim that between 5,000 and 8,000 new parts numbers are being created for every new vehicle (Kühlwein *et al.*, 1999). However already existing part numbers of other vehicles are not replaced by the introduction of a new model. Spare parts logistics has therefore developed into a key success factor within the automotive sector, since there are several aggravating conditions (Kühlwein *et al.*, 1999). First of all, different parts show different demand structures. Secondly, conventional forecasting methods seem to fail for products with high replenishment cycles. Seasonal fluctuations increase the demand uncertainty in spare parts management (Kühlwein *et al.*, 2003). In addition, there are conflicting life cycles between the product car and certain car components and parts, such as microprocessors and other electronic devices. The differences between these life cycles complicate the provision of spare parts and replacements.

> *The speedy innovation desired by the automotive industry and necessary for competitiveness is a direct contradiction to the requirements of long-term supply. Innovations are mainly driven by mass markets such as information technology, for example. These markets are characterised by their short product life cycles. The semiconductors required for these are produced using continually new methods. The automotive industry cannot utilise the capacities of out-of-date manufacturing facilities economically and thus cannot guarantee the long-term supply of electronic components.*
>
> (Hella KG Hueck & Co., 2003. p.2)

For electronic devices, such as an ECU, the extremely low post-serial volumes, compared to the large amount of products required in the serial production, ask for new strategies in spare parts management. The Hella KG has recognised the issue of the long-term supply of electronic devices. The company therefore takes into account 'design for remanufacturing', the creation of 'master units' which cover the functionalities of different versions as well as compatibility of follow-up generations (Hella KG Hueck & Co., 2003).

5.3.4 Threats and Opportunities to the Automotive Aftermarket

Aftermarket Profitability

According to Lewis, G. (1991), research has shown that an improvement in the quality and durability of automotive parts is more than offsetting aftermarket demand increase, due to the augmentation of the vehicle park. Since vehicle manufacturers demand higher quality of original equipment, they cut off aftermarket demand, particularly with regard to wear-and-tear parts. As an example, in the 1990s, the lifespan of a shock absorber increased from 70,000 to 150,000 km, the durability of a spark plug from 10,000 to 30,000 km and the steel exhaust's lifespan from 50,000 to 80,000 km (Lewis, G, 1991). It seems, as if vehicle manufacturers need to find a balance between customer expectations and corporate needs. On the one hand, customers should not be disappointed by an inferior quality or a low durability of parts in the car, particularly with regard to high-end car brands. There have been cases in which a high-quality original equipment part has offset aftermarket demand. A good example is a phenomenon, termed the 'stainless-steel trap' by the industry: the making of very durable exhausts which 'kill' the replacement market (Chew, 2002a).

On the other hand, the aftermarket business is a very lucrative sector, since cars last longer and therefore need more replacements to keep them on the road. Car retailing accounts for just 3% of the automotive profits pool (considered over a period of ten years), whereas body shop and mechanical repairs, as well as replacement parts amount to nearly a third of the whole vehicle's expenditure (Procter, 2000). Moreover, given the fierce competition within car retailing, it is expected that profitability in car retailing will further decrease. This situation has lead to a re-thinking in automotive retailing, hence new retailing concepts have developed (e.g. Nieuwenhuis and Wells, 1999, 2002; Wells and Nieuwenhuis, 2000).

However, not just the aspect of profitability has increased the industrial players' interest in the automotive aftermarket. According to the SAP AG (2000), the after sales business is seen as a crucial period of the car life cycle. After sales services may be perceived as a tool to guarantee customer satisfaction, even after the buying decision has been made.

In addition, there could be an information feedback from defect analyses in the aftermarket to the current vehicle production. This information may directly influence and improve current production processes (e.g. new development, 'face lift').

Product Longevity and Remanufacturability

As discussed in Chapter Three, from a sustainability perspective, products should be made as durable as possible. From a business perspective, however, there are two factors which influence product longevity and remanufacturability. Car engineers and designers wish to incorporate durable parts into the vehicles, which need to meet stringent quality requirements (Chew, 2002a). This harmonises well with the idea of sustainable product design. However, car parts designers and purchasing agents of the serial production process need to make a decision between a generally more expensive part, which may facilitate disassembly or recycling of the final product, and a less costly, but less eco-friendly piece. Interviews within the case study on car electronics have revealed that designers, engineers and parts procurement departments have to stay within a certain budget. They therefore often refer to the cheaper, but less sustainable option. "The development of ECUs is not only guided by aspects of safeguarding functionality and permanent function safety, but also by the cost aspect. These basic conditions can result in solutions for series production unit designs that contradict optimum post-serial supply concepts (e.g. welded housing)" (Hella KG Hueck & Co., 2003, p.6).

A particular determinant in this decision process seems to be limited time employees remain in a specific job position. Hence, there is a disconnectedness of an individual employee's work and the aftermarket responsibility. An aftermarket expert of the electronics Case Company comments:

> *'Design for recycling' is included in all our contracts with vehicle manufacturers, but no one cares about it. If we tell a vehicle manufacturer's buying agent that an eco-designed connexion with screws is two cents more expensive than the conventional connexion, the buyer thinks to himself: I'll ignore that, in three years time I won't be in this job position any more.*[20]

[20] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at case Company D, July 2003, translated from German.

However, very importantly, their decision has an influence on aftermarket management. Very durable products cut off aftermarket profits and cheaper parts installed in components may complicate disassembly within future remanufacturing operations. Also, ignoring the 'design for disassembly' approach may even lead to a scarcity of spare and replacement parts for the aftermarket. The clash between aftermarket interests and the concerns of vehicle designers will be further discussed on the basis of case study examples in Chapter Nine.

Demand Forecasting

One of the major issues within aftermarket management is the forecasting of current and future demand. A particular uncertain factor is the nearly random demand of spare and replacement parts, low volumes in some cases, as well as the discontinuation of certain parts and components (final demand forecasting). As a matter of fact, historically-based demand patterns seem to be the main forecasting strategy among aftermarket players, whereas the life cycles of individual parts are not considered (SAP AG, 2000). As the literature in Chapter Two has shown, forecasting has developed into a determining factor of success within the remanufacturing sector, since not just aftermarket demand has to be anticipated, but also the used product return flows. Many theoretical forecasting tools have been provided by academic research through mathematical modelling and simulation. However, the limited empirical applicability of such methods has already been questioned in Chapter Two.

5.3.5 The (European) Remanufacturing Sector

Size and Structure

The size and importance of the automotive remanufacturing industry is very ambiguous and unclear (Lund, 1996; Toussaint, 2003). This is largely determined by the 'shadow existence' this industry maintains, as Chapter Two has briefly outlined.

> *The size of the market for remanufactured parts is almost impossible to quantify due to the diversity of sources and lack of data on output, especially as the operators concerned are often very small workshops. This is partly due to the high rejection rates: the number of exchanges units collected does not bear any relation to the final remanufactured output.*
>
> (Lewis, G., 1991, p.58)

Lewis, G. (1991) has undertaken research on the European automotive aftermarket with a particular focus on (West) Germany, France, Italy and Spain. A specific section is devoted to engine remanufacturing. In Germany, Lewis claims that remanufactured engines occur from various sources. Firstly, from the vehicle manufacturers, the most important source, who recover the engines in their own facilities and sell these only through their dealer network. Moreover, components such as clutches, radiators, fuel pumps, carburettors and brake parts, are remanufactured within the plants of the original equipment supplier. Core sources include the dealer network, independent garages as well as the supplier's own repair shops.

According to Lewis, G. (1991), around 50% of the parts being remanufactured by original equipment suppliers are returned to the vehicle manufacturer for sale through their dealer network. The remainders are sold through independent channels and the suppliers' channels. This confirms what has been briefly noted in Chapter Two. As opposed to the remanufacturing industry in the United States, original equipment remanufacturers are more dominant in the European remanufacturing sector.[21]

[21] According to Guide (2000), industrial remanufacturing by OEMs accounts for less than 5% in the United States.

Product Quality

This section seeks to identify the qualitative performance of remanufactured automotive parts and components. According to Hadingham (2003b), remanufacturers may not be obliged to comply with current emission standards, but they have to meet those which were in place at the time the engine was originally produced. Hence, it is easier for remanufacturing firms to claim they 'improve' or 'upgrade' their engines during the recovery process, since standards at the time of the original production were much lower. The Volkswagen AG argues that the remanufacturing of parts and components is 'not just a 1:1 restoration' of a part with regard to type and model, but much more. During remanufacturing, parts and components are upgraded qualitatively by applying the most recent level of technology. In individual cases, a remanufactured part may even be more suitable than the old, previous part (Hallatschek and Stegen, 2003). The industry further claims that remanufacturers are not just technically capable of bringing parts and components to the original specification, but they are able to upgrade the product to a higher standard.

However, there is another debate within the industry. In order to protect their position in the remanufacturing market, original equipment manufacturers, such as Ford and Valeo, claim that only the original manufacturer of the component is able to produce a top quality remanufactured part. Independents counter this is untrue, since during their remanufacturing process, design errors may be reversed, so that to prevent future product failure. "This is because the remanufacturer is in a position to re-engineer the OE product, eliminating any problems that have been identified in the original OE design" (Phillips, 2001, p.27). Hancock (2004) confirms that "incidentally, remanufacturers are highly skilled engineers and often recognise weakness in the original design which can and is often engineered around. Sadly, the VMs or OEMs take little note of these failing and may even try to deny such problems".[22]

Original equipment manufacturers try to increase their market share in a business, which has been in the hands of independents for a long time. While they argue to provide qualitatively superior products to the independents, it is rather possible that the

[22] As subsequent chapters will demonstrate, engineers in remanufacturing plants are in fact highly skilled.

independent sector relishes more freedom with regard to new parts being built into products. Other sources deny technical improvements.

> *Our 'old' engines used leaded petrol. Due to environmental reasons, this fuel is now prohibited. As a result, we were forced to change the valve seat inserts in our engines. The old inserts used to burn through with unleaded fuel, hence they were replaced by ones made of tempered steel. This change was also introduced in the engine remanufacturing operation. Now, remanufactured engines operate using unleaded fuel without any problems. However, as far as I know, there were no other technical changes with regard to exhaust norms (environmental regulations or other legal demands) which were applied within the remanufacturing operations. By installing a technically upgraded* [compared to the previous engine] *remanufactured engine, tax savings for the car owner are not feasible either.*[23]

Mechanical versus Electronic Remanufacturing

In the past, remanufacturing operations have been focused on mechanical components. However, with an increasing electronic content in cars and particularly the rising use of 'mechatronic systems', which combine mechanical elements, electronics and informatics in one product, more and more remanufacturers consider to extend their product range. The Robert Bosch GmbH, for example, offers motor control units, which are remanufactured in two plants: Madrid and Reutlingen (Robert Bosch GmbH, 2001/2002). One of the major distinctions between the remanufacturing of a mechanical component (e.g. a clutch) and an electronic component (e.g. a control unit), is the fact that mechanical remanufacturing is visible. As Chapter Two has shown, the typical process includes surface finishes (grinding, abrading, honing) and the replacement of parts (liners, bushes, springs). Moreover, there has been a long history of mechanical remanufacturing. However, this is not true for radios, which have been repaired since decades and remanufactured since approximately ten years.

[23] Quoted from personal communication (E-Mail) with the Manager Technical Support Chassis at Case Company A's Global Warehouse, June 2003, translated from German.

Electronic device remanufacturing is gaining growing importance in the automotive remanufacturing sector. The Automotive Parts and Rebuilders Association (APRA) held the first workshop on 'Electronics and Remanufacturing' in 2003, which was destined to discuss how the increase of electronics in cars will directly and indirectly affect the remanufacturing sector. Moreover, this seminar aimed at building a basis to create an electronics division inside APRA. This example shows that only now, remanufacturing trade organisations are beginning to establish divisions focusing on electronic component remanufacturing. It also demonstrates that associations, such as APRA, perceive this topic as so significant that they aim at establishing a separate department. In April 2003, the German electronics manufacturer *Hella KG Hueck & Co.* began to offer garages remanufactured engine control units and the possibility of repair. "This means that the renowned automotive parts supplier is now offering a cost-effective alternative to new parts with a strong element of recycling" (Schwarck, 2003b, p.8).

As previously noted, electronics remanufacturing is less visible, since it may include processes such as the application of new software. It may therefore be also less comprehensible. In 2003, the CarCareCouncil (2003) argued that finding a way of remanufacturing electronic and hydraulic systems has been one of the biggest challenges in the automotive remanufacturing sector. There are certain issues, which make this type of remanufacturing more difficult than mechanical remanufacturing. On the one hand, independent remanufacturers struggle to gain access to design information and software. Mechanical components may be disassembled and carefully examined. This is common practice among European independents. Mike Searle confirms that "[...] in the US, remanufacturers have access to original equipment suppliers' spec sheets, whereas over here, we have to strip engines down and find out for ourselves" (in Phillips, 2001, p.27). Detailed design information is rarely available to independents. "It is therefore necessary to investigate and 'reverse engineer' the system in order to gain enough knowledge to attempt remanufacture" (Walker, 2003, slide 50). Since high levels of skill and experience are necessary to perform reverse engineering processes,

this may be a critical factor to costs. Original equipment manufacturers however, object that high remanufacturing standards can be achieved through 'reverse engineering'.[24]

> *Independent remanufacturers decreasingly understand electronic control units. Nowadays, there are much smaller printed circuit boards, which are less and less comprehensible. Also, independents can only undertake real-time simulation* [simulating a part fitted into and working in a car], *nothing more. They just can't do it. They do not have access to testing and gauging equipment, algorithms and product documentation. They will all go bust, that's obvious. I say it like this: if they want to carry out this business seriously, they'll collapse.*[25]

5.4 Engines and Electronic Devices

This section aims to provide an understanding of the characteristics of the two product groups, engines and electronic devices. The discussion on engine manufacturing and the increasing significance of electronic components will assist to see the case study research in Chapters Six and Seven in an industrial context.

5.4.1 Engine Manufacturing

Engine manufacturing, which comprises the machining of the cylinder block, cylinder head, engine assembly and the (hot) test, is probably one of the last manufacturing activities, which is still mainly undertaken by vehicle manufacturers. Most of the parts and components needed in the assembly of a vehicle are supplied, and so are many engine parts. However, the picture of the engine manufacturing sector is not clear, instead, it becomes less and less transparent (Hadingham, 2003a). In the course of this research, initial background research was undertaken in a high-volume engine manufacturing plant. The author spent seven days within the plant to conduct and

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[24] 'Reverse engineering' is characterised by the complete disassembly of a part or component in order to detect the product's composition or mode of operation. Reverse engineering has been successfully applied with regard to mechanical components. Within this procedure, wear patterns have helped in the examination process. Electronic components, however, are more difficult to understand and reconstruct, since software plays a major role, wear patterns as such do not occur and the 'history' of the product is therefore less comprehensible.

[25] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at case Company D, July 2003, translated from German.

'engine teardown training'. There was also the opportunity to observe the engine manufacturing process.

Since a uniform understanding of engine terminology had to be developed, the following classification was created. Simpson (1998) explains that a product family comprises a group of related products that derive from a common platform. A platform is hereby characterised as the 'common technological base'. Depending on the manufacturer, an engine family comprises in-line as well as V-engines. However, some manufacturers may create a V-engine family. Simplified, an engine family may share the same cylinder block, for example. The in-line cylinder block design may therefore be applied to an in-line four-cylinder, but may also be extended to an in-line five- or six-cylinder engine. For a V-engine, the cylinder block is shortened by one cylinder and 'doubled' to create a V-6 engine. A good case for an engine family is the Ford Duaratec engine family, which has five family members. This engine family comprises the Duratec 20 (2.0-liter, in-line, four-cylinders), Duratec 23 (2.3-liter, in-line, four-cylinders), Duratec E (low emission engine and a variant of the Duratec 23), Duratec 30 (3.0-liter, V-6 engine) and the Duratec 35 (3.5-liter, V-6 engine) (Jewett, 2003). These engines are used in different car models.

The next level of engine classification is the engine 'model' category. It was decided to base this category on a combination of two characteristics: the engine layout (V-engine or in-line) and the fuel type. It may indicate whether the engine is fuelled by petrol, diesel or gas. Every further level of engine classification has been decided to be identified as 'variant'. This categorisation is based on the criteria that the difference between two engines is so significant that it has an impact on the remanufacturing process. Different cylinder capacity sizes are therefore variants of one particular engine model. As an example, the Ford Zetec engine family comprises a diesel and petrol model. Moreover, the petrol model can be divided into several variants, including the 1.6 litre, 1.8 litre and a 2.0 litre engine. Each of these variants can be further broken down into sub-variants, such as differences in the wiring harness, additional features for installation in different car models, and many more. However for the reason of

simplification, the main categories within this thesis are engine family, model and variant. Table 36 summarises the terminological framework for this dissertation.

Engine...	Defining Characteristics	Example for Distinction or Commonality
...family	▪ Related products ▪ Deriving from a common platform (common technological base)	▪ Sharing the cylinder block
...model	▪ Engine layout ▪ Fuel type	▪ V- or in-line engine ▪ Petrol, diesel or gas
...variant	▪ The difference between two engine models is as such that it has significant impact on the remanufacturing process	▪ Cylinder size
...sub-variant	▪ Group of engines that belongs to one variant	▪ Wiring harness ▪ Right-hand drive/left-hand drive ▪ Automatic or manual gearbox

Table 36: Summary of Engine Terminology

During the background fieldwork, the engine manufacturing process of one in-line, four-cylinder engine was observed, including the preceding machining processes. Machining takes place simultaneously to engine assembly and all parts, apart from the connecting-rods remain on stock for 24 hours before being assembled into an engine. Machining throughput times were the following:

- Camshaft: 2.5 hours
- Connecting-rod: 4.0 hours
- Crankshaft: 3 hours
- Cylinder block: 1.5 hours
- Cylinder head: 5.0 hours
- Ladder frame (main bearing, supporting the crankshaft): 10 minutes
- Cylinder block and matching main bearing: 1.5 hours

Machining processes are fully automated. The cylinder block machining line, for example, processes 400 pieces at the same time. Around 250 operational steps are accomplished in an average time of 21 seconds per cycle. The main bearing machining line works on 70 pieces at once at 21 seconds per cycle. Afterwards, cylinder block and main bearing are joined and machined together. The engine assembly process, however, is less automated than the parts machining and there is a strong involvement of manual work. Yet, compared to a remanufacturing operation, engine manufacturing still produces high volumes.

Interviews with industry experts have revealed that most vehicle manufacturers still manufacture their own engines and have not outsourced this operation. However, due to cost pressure, co-operations are increasing:

> *Many car companies are now co-operating in the development of engines to achieve higher volume potential against which to amortise both the development costs and the tooling which are increasingly a heavy burden. The price of cars and the costs of engines that they use are showing any significant increase in real terms despite the extra costs involved in meeting noise and emissions regulations. This does mean that car companies are looking at many ways to reduce their overall cost.*[26]

There are examples of co-operations between vehicle manufacturers, such as the case of Jaguar. The brand has lost sales, because it lacked diesel engines. Hence, Jaguar cars have received the first V-6 common-rail diesel engine by 2004, which is manufactured by a Ford and PSA/Peugeot-Citroën partnership (Wernle, 2003). Nick Scheele, the Ford president, explains that this joint venture's objective is to become world leaders in engine manufacturing. Engines are designed to fit different Ford and PSA brand vehicles with the V-6 engine to be built into Peugeot and Citroën models (Wernle, 2003). The V-6 engine will be manufactured in Ford's new Diesel Business Centre in Dagenham, England, and may find further application within other vehicles, such as to replace the BMW diesel engines in Land Rover vehicles (Wernle, 2003).

[26] Quoted from personal communication (E-Mail) with Edward J. Hadingham, the Managing Director European Operations of Power Systems Research in Brussels, Belgium, September 2003.

> *It is still the case that most car companies do make their own engines but co-operation has been going on for quite some time. For example, an engine plant in Douvrin in France jointly owned by Peugeot and Renault has been producing engines for both companies more than 10 years. Volvo had an interest in this plant in its early days but sold it to the other two parties.*[27]

However, there does not seem to be a totally independent engine supply industry, with different vehicle manufacturers as customers. "There is one totally non-captive engine supplier that comes to mind and that is VM Motori in Italy. They supply the diesel engines for the Chrysler Cherokees and Voyagers built in Austria. VM Motori was part of Detroit Diesel which became part of DaimlerChrysler but is now independent – but can it be considered as truly independent supplier?" (Hadingham, 2003a). The industry expert hereby poses an interesting question, which may be not fully answered at this point.

However, there is a clear picture developing with regard to the cross-application of engines. In other words, engines that are used in different car models and may find application in cars of different brands and manufacture are showing similar developments to the 'platform strategy' applied within vehicle manufacturing. This platform strategy aims to produce as many models and variants from as few platforms as possible (Nieuwenhuis and Wells, 2002).

> *There is also a market in the normal supply of engines from one car company to another to fill gaps in the range etc. For example the Volvo S40 uses a Mitsubishi engine and is built by Ned-car using a Mitsubishi Gallant platform. Earlier versions of the car used Renault engines and transmissions. Up to quite recently, the Opel Omega diesel engine was supplied by BMW. Most of the Vauxhall/Opel diesels are supplied by Isuzu – in which GM has a controlling stake. And so on – there are many examples of non-captive and semi-captive engine supply within the car industry in Europe – and world-wide.*[28]

However, despite the fact that many vehicle manufacturers are now co-operating in the development and manufacturing of engines with product application in more than one car model or brand, overall engine variants are increasing. The following section

[27] Quoted from personal communication (E-Mail) with Edward J. Hadingham, the Managing Director European Operations of Power Systems Research in Brussels, Belgium, September 2003.
[28] Ibid.

explains how and why engine variants emerge. It also outlines why high product variation has become and issue for the automotive aftermarket.

5.4.2 Progression of Engine Technology and Variety

According to Hadingham (2003a), it is very difficult to map the rate of change of engines with specific data. With the aim for better fuel economy, in a very short timeframe, petrol engines have developed from carburettor over throttle body injection, to individual port injection and finally to direct injection. Diesel engines have gone from an integrated direct ignition system over direct injection systems to unit injectors and common rail injection systems within a similar timeframe (Hadingham, 2003a).
Hadingham (2003a) further outlines that car companies do not invest heavily into research and development of engines. Instead, most impulses for technological alterations arise from legislation. The work by Power Systems Research (2003) demonstrates that from 1976 to the year 2002, engine technology has increased, while durability for both petrol and diesel engines has improved. Technological progressions include reduction in emissions, increase of horsepower per unit of weight, as well a decline in fuel consumed per unit of power (Power Systems Research, 2003).

> *There are many more variants of each engine now because with electronics it is easier to produce these variants. The problem of the aftermarket is to identify the common features of engine families and hold stock to this level until the very last minute and finish it off to order. I have discussed this with a number of engine re-manufacturers who see this proposal as a fundamental change to their current working practices and are loath to adopt it.*[29]

Table 23 shows how engine variants have increased over the years. The source of the data does not capture minor rating variants and also generalises by subsuming engines with the same power and the same 'kit'[30], hence the true picture is much more dramatic. However, the table shows that between 1980 and 2003, the number of engines produced world-wide has increased by nearly eight times. The volumes of engines have expanded

[29] Quoted from personal communication (E-Mail) with Edward J. Hadingham, the Managing Director European Operations of Power Systems Research in Brussels, Belgium, September 2003.
[30] The engine 'kit' is defined as the number of parts which are needed to fit the engine into a vehicle, for example the alternator, the exhaust manifold or the starter motor.

from an annual output of over 12 million in 1980, to an estimate of over 54 million by the end of 2003. In the same period of time, however, the output per engine model has dramatically decreased from an average of 76,000 (1980) to just 42,000 engines per model in 2003.

Year	1980	1990	1995	2000	2003 (estimate)
Engine Models	163	790	865	1,095	1,281
Volume	12,413,351	39,199,466	40,648,374	48,960,172	54,441,178
Volume/Model	76,156	49,620	46,992	44,712	42,499

Table 37: Car Engine Production World-Wide for Cars, Minivans and Sport Utility Vehicles (Source: Hadingham, 2003a)

According to Hadingham (2003b), variation in engine *manufacturing* can be managed easily. The aggregates are machined and assembled in families, which share the cylinder block, the cylinder head and the crankshaft. Consequently, the same machining line may be used for a variety of engines, as long as holes remain at the same place.

> *Yes you rightly note that engine specifications are changing much more rapidly now. However, many of these changes are superficial and don't affect the core of the engine. Some are even simple programming changes in the ECU to produce a different performance specification. The trick is to produce a family of engines off the same core block, crank and head. It is important to costs to be able to put this family of engines through the same machining lines even if they have different bore and stroke. The trick here is to leave the major holes (cylinder bore, crankshaft and camshaft positions) in one place and if necessary move the metal around to strengthen and stiffen the engine allowing it down the same machining line.*[31]

As a result, within the high-volume engine assembly processes, even mixed batches may occur, since the engines are equipped with a barcode or may be identified through sensors. According to this barcode the matching parts (e.g. pistons) are delivered to the assembly line for built-in. In this way, engines are assembled-to-order and delivered to

[31] Quoted from personal communication (E-Mail) with Edward J. Hadingham, the Managing Director European Operations of Power Systems Research in Brussels, Belgium, September 2003.

the vehicle assembly plant for the right vehicle, in the right order and at the requested time.

The situation is different for remanufacturers. Firstly, Chapter Two has outlined that remanufacturing plants are usually less automated than high volume engine manufacturing plants. Secondly, a remanufacturer deals with more than one engine family or generation at a time. It therefore seems as if the secret of managing a successful engine remanufacturing operation lies in managing variety (variants). Hammond *et al.* (1998) confirm that managing variety has developed into a key competence within the remanufacturing sector, since remanufacturers suffer from dealing with different part generations and variants (product proliferation). Tim Rahill, manager of manufacturer and remanufacturer Delco Remy, further explains how product proliferation evolves. "OE producers will select up to four or five starter or alternator suppliers for any new model. These in turn will each require regular on-going modifications – where even the smallest change will create a new part number – so the ratio of 10:1 can, in some instances, expand to 50:1" (Tim Rahill in Phillips, 2001, p.27). As a result, a key prerequisite is to reduce the number of different product variants by creating one product that fits into different car models. Larger automotive engine remanufacturers therefore try to subsume as many engine variants into one 'remanufacturing group' so that the process is becoming more standardised and efficient.

5.4.3 Electronic Devices and Components

The supply chain for electronic components is different to the engine supply chain. One of the main differences is the fact that vehicle manufacturers have outsourced most of their electronic production. Trends towards outsourcing parts and component operations have always taken place in the automotive sector, but the biggest phase began in the 1990s. "[...] as the new millennium begins, carmakers around the world are closing or selling off all but the most vital of their parts and component operations, betting they can cut costs, improve quality and get more state-of-the-art goods from outside suppliers" (Eisenstein, 2000, p.28). Particularly captive electronics producers have been

outsourced by most vehicle manufacturers. The General Motors Corporation has released its parts manufacturer Delphi in 1999, with the Ford Motor Company following in 2000 (Eisenstein, 2000). There are several benefits to vehicle manufacturers for outsourcing parts manufacturing. Apart from revenues generated from the sale of the captive supplier, they assume that the segregation benefits the innovation process, since captive plants are usually not exposed to market pressure. However, power relationships may also change. Additional customers (vehicle manufacturers) may place orders with the outsourced electronics manufacturer. Loyalty to the 'old' partner may therefore decrease. Despite being given long-term contracts by Ford and General Motors, respectively, Delphi and Visteon have therefore faced increasing competition over time. As noted before, suppliers are under tremendous (cost) pressure. "For small suppliers, the pressures have often proved too much. Since 1990, nearly 90% of world automotive suppliers have merged, sold out or simply shut their doors, notes a report from consulting firm, International Business Development. But for those that survive [...] the opportunities are significant" (Eisenstein, 2000, p.28).[32]

The outsourcing of supplying companies also has strategic consequences. Electronic sub-suppliers, for example, often provide components for industries outside the automotive sector, such as the communication sector (e.g. mobile phones) or the consumer goods sector (e.g. household appliances, computers), as shown in Figure 14. Other sources, however, list a growth with regard to the automotive industry's demand for passive components. In France, for example, Renault and PSA Peugeot/Citroën are increasingly integrating passive components in their production (Anonymous, 1997). Moreover, they are delegating more subassembly activities to their principal suppliers Valeo and Delphi (Anonymous, 1997).

[32] However, there are also opposite trends. Toyota has created an in-house capability for electronic components, in order to reduce its dependence on its long-term supplier Denso. This proves the point made by Ahmadjian and Lincoln (2001), who claim that according to transaction-cost economics, a company is more likely to incorporate certain activities if hazards of opportunism rise. The changing environment of electronic component manufacturing and supply has provoked Toyota to bring electronics under administrative control.

Electronic component suppliers (manufacturers, importers or distributors) may therefore demonstrate low loyalty towards the automotive industry, but with an increase of electronics in cars, their importance will increase. Thierry Morin, automotive supplier Valeo's chairman, explains that from Valeo's ten industrial branches, electrical and electronic areas grows fastest (Thierry Morin in Chew, 2002b). The SMMT further emphasises that the electronic component sector is fast-changing, particularly with regard to new technologies in the area of satellite navigation systems, TV and game consoles.

However, one employee of Case Company D (electronic supplier) claimed that the trend of outsourcing is regressive, since vehicle manufacturers have now perceived the disadvantages of outsourcing. "Vehicle manufacturers want to understand what the suppliers talk about – particularly in the electronics sector" (Manager, IT Integration).

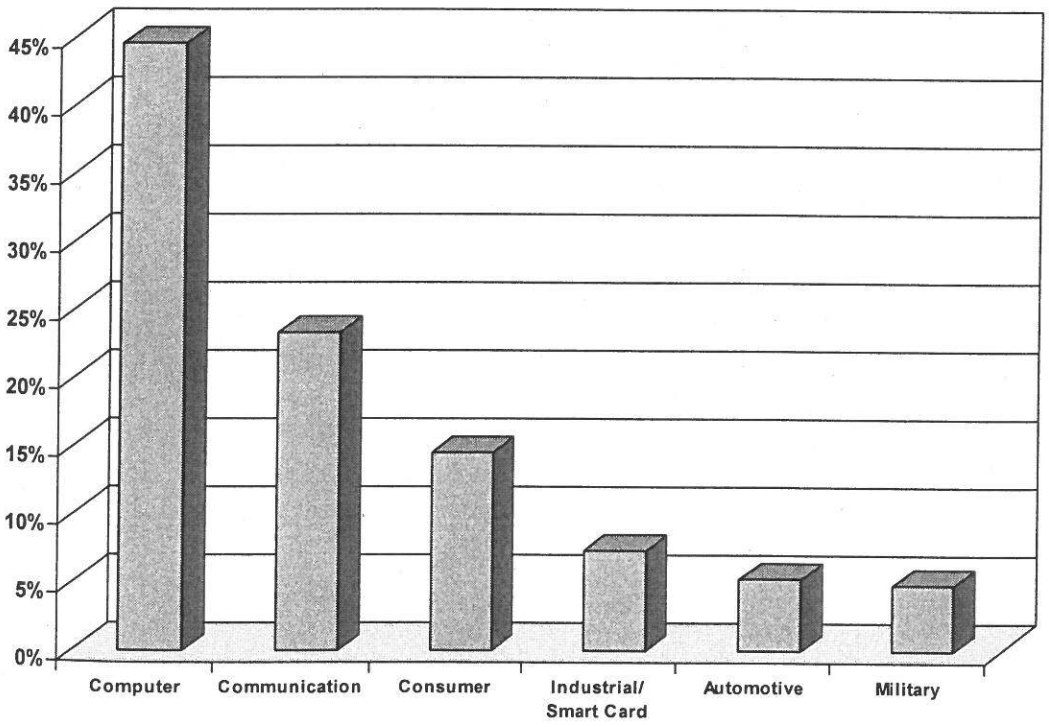


Figure 14: The Chip Industry: Main Application Segments
(Source: figures from Gortol *et al.*, 2003, slide 6)

As a consequence, the vehicle manufacturer's influence on parts and component suppliers is reduced with an increase of the supply chain dispersion, as it is the typical case of the complex automotive supply chain.[33]

A further distinction between the components engine and electronics is the time-to-market, which has been identified as a key advantage in so-called 'fast cycle' industries with product life cycles of more or less two years (Stalk and Hout, 1990; Stalk, 1988; Datar *et al.*, 1997). The total production cycle time for an electronic chip may only comprise eight to fifteen weeks (Gortol *et al.*, 2003). A working life of a silicon technology generation is between four and seven years, whereas the working life of the associated production machinery is five to seven years (ZVEI, 2002). On the other hand, it needs several years to design a car, whereas the product itself (vehicle) has an average lifespan of up to two decades.

[33] Anonymous (1997) describes this complexity as follows. "Up the chain from OEMs are subassembly suppliers who subcontract to subsystem suppliers, who in turn call on component suppliers (manufacturers or importers/distributors). To reduce the time to market (and time to volume production) of end products, OEMs are developing close partnerships with their suppliers to anticipate and influence upstream design. At the same time, they want to deal with a smaller number of suppliers" (no page given).

5.5 Conclusion

This chapter has outlined the structure and characteristics of the automotive supply chain and the aftermarket. A particular emphasis was put on the threats and opportunities to the market for remanufactured goods, such as the question of profitability or product longevity.

Thereafter, the chapter resumed the discussion of Chapter Two, which had described the players in the remanufacturing sector, by taking a broader perspective of the European remanufacturing sector. Its size and structure, the product quality, as well as the differences between mechanical and electronic remanufacturing were discussed. The chapter concluded by outlining the product characteristics of car engines and electronic devices.

Overall, the chapter aimed at embedding the research into an industrial context. The subsequent Chapters Six, Seven and Eight have therefore been put into an industrial framework.

Chapter Six
OEM Engine Remanufacturing: An In-Depth Case Study

6.1 Introduction

This chapter presents the results of the first in-depth case study of the research, which was conducted within the facilities of a major car manufacturer. The company's request for anonymity means that it will be only identified as 'Company A' in the following. The case study research was carried out over a period of five months. Three venues were investigated, which also represented three echelons of the supply chain for remanufactured engines. The venues included the engine remanufacturing plant, the Global Warehouse, as well as the Headquarters. At the remanufacturing plant, used engines were remanufactured, hence the operational processes could be observed and analysed. These engines were delivered to the Global Warehouse for storage and further distribution. As a result, the author was able to obtain more information on the product and the financial flows along the supply chain for remanufactured engines. At the last venue, the vehicle manufacturer's Headquarters, data on the pricing of remanufactured goods was obtained. Moreover, broader aftermarket issues, such as the increase in inventory levels as a result of increases in the product variety were investigated.

This chapter has several objectives. Firstly, it examines and analyses the basic principles of engine remanufacturing from an OEM perspective. It focuses on the take-back of the used products, the individual steps of the recovery process, as well as the interplay between the supply chain members. Secondly, it provides the first steps to answering Research Questions 1 and 2 for a specific case of engine remanufacturing. Thirdly, the chapter seeks to provide the database for the discussion on the modelling of the closed-loop chain for automotive engines (Chapter Nine). In addition the data presented in this chapter provides the rationale for automotive remanufacturing (Chapter Ten). Moreover, it aims to identify major obstacles within the in-plant remanufacturing processes, as well as to outline the differences between manufacturing and remanufacturing.

6.2 A Closed-Loop Supply Chain for Passenger Car Engines

6.2.1 General Case Description

One of the main characteristics of remanufacturing is the incorporation of used products, parts and components in the manufacturing process of 'new' products, as already pointed out in Chapter Two. The activities incorporated in taking back a used engine and exchanging this engine for a remanufactured aggregate are therefore often called 'exchange process', 'exchange transaction' or 'net exchange business' (Krupp, 1993). The exchange business differs to a large extent from general manufacturing processes (Guide, 2000; Tibben-Lembke and Rogers, 2002; Rogers *et al.*, no date given). This chapter puts an emphasis on the general characteristics of exchange businesses. The main objective is to portray the characteristics of this rather 'unconventional' type of business. Unconventional, since it differs from conventional, high-volume engine manufacturing.

The data was collected through a total of sixty-four semi-structured and structured interviews. Interviews took between 20 minutes and up to several hours. Interviewees originated from all functional levels, including executives (centre manager; head of department), middle management (planners; administrators), as well as workers (assembly-line staff; warehousemen). As Chapter Four has pointed out, the application

of semi-structured interviews was seen as particularly beneficial, in order to uncover new evidence for the re-direction of the overall line of enquiry.

Further data collection methods that were applied within this case study included (process) observation ('walking the process') and the collection of secondary data, such as company reports or presentations. To ensure the overall validity of the research, findings gathered at one level of the supply chain had been verified at the two additional venues. This verification was perceived as particularly relevant, since the author found that occasionally, interviewees were not fully aware of processes elsewhere.

Vehicle Manufacturer A is located at the upper end of the market and produces high quality and luxury cars with a reputation for product longevity. Several implications arose from those characteristics, which will be outlined throughout the chapter. Furthermore, this study was limited to engines of passenger cars and small commercial vehicles. This limitation had to be made to narrow down the overall scope of the study. Two further reasons for this limitation included the fact that truck engines were remanufactured at a separate remanufacturing plant and secondly, the market for truck engines differs to a great extent from the passenger car segment.

6.2.2 Characterising the OEM Exchange Processes

There are several aspects that are essential to the understanding of the OEM exchange business. These characteristics are discussed in this section. They are not believed to be specific for the Case Company, since similar practices were observed at other OEM remanufacturers (see, for example, Langella, 2003). The observations have also been verified in interviews and informal discussions with industry experts at the automotive remanufacturing trade fair in the Netherlands (ReMaTec 2003).

The first characteristic of an OEM exchange process is the financial incentive, which is provided for the used product (core), the so-called rebate. Within the Case Company, this rebate was between 20% and 40% of a remanufactured engine's price. The rebate represents an incentive for car users to purchase a remanufactured engine from the OEM, since the old aggregate is traded in for a remanufactured good. For the OEM, on

the other hand, the rebate ensures a product return for every unit sold. In this way, used product returns are managed and monitored. Guide and Pentico (2003) confirm that "product returns may be mandated or encouraged by legislative acts, but firms may still encourage the returns of products in known condition by offering incentives" (p.30). However, it may be assumed that this characteristic is typical for OEM exchange processes and very large independent remanufacturers, but not for small independents. A field visit to an independent remanufacturer has shown that the customer receives the identical product and is therefore only charged for the remanufacturing service. Hence, no 'exchange' as such takes place. Within OEM remanufacturing, the customer usually receives a product from stock which is not identical to the core that was returned (see also Table 2 in Chapter Two). However, since the investigation of the independent sector has been limited within this dissertation, this assumption has to be further examined.

In addition, there is the principle of the 'equal exchange'. This principle indicates that the customer may only purchase an engine of the same variant than the core that was returned. The vehicle manufacturer hereby avoids that customers abuse the opportunity of buying a remanufactured engine for a reduced price, by handing in less powerful used engines and purchasing more valuable remanufactured engines, such as an improved engine variant of a later series. This aspect seems to be less critical in the engine segment, since technical amendments between variants often inhibit the installation of a new version. However, as Chapter Seven will outline, this characteristic is particularly relevant in the electronics segment, in which devices are often interchangeable.

The last important aspect in the exchange process is the warranty, which is given for remanufactured goods. Since remanufactured products are perceived 'as good as new', there are identical warranties for remanufactured engines than there are for new engines (two years, at the time of the research).

6.2.3 The Closed-Loop Supply Chain and the Process of Exchange

At the time of the research, the Case Company utilised its forward distribution network as collection network for used engines. As a result, many issues which have been associated with reverse logistics in Chapter Two (e.g. collection structure complexity; integration of forward and reverse flows) had been minimised in Case Company A.

Figure 15 shows Company A's network of logistics and distribution centres in the case of Germany. There was one Global Warehouse and five distribution centres throughout the country. All 1,200 German subsidiaries and dealers were tied to the distribution centres. Each distribution centre covered between 17 and 30 daily transport routes (122 routes in total), which supplied the retail level (subsidiaries and franchised dealers) with goods that had been ordered from the Global Warehouse. The Global Warehouse therefore represented a logistics hub, which received and distributed approximately 1,500 tons of parts and components daily. Its inventory was worth around €2.5 billion. An additional €500 million worth of stock were stored at each distribution centre.

The Global Warehouse also stored approximately 8,000 remanufactured ('finished') passenger car engines, which accounted for seven to eight months of the remanufacturing plant's output. It received remanufactured engines from the remanufacturing plant in daily intervals. Due to the large amount of goods that were distributed every day, the cost of a single product (e.g. cores or remanufactured engines) was embedded in the overall costs and could not be specified by the interviewees. At the time of the fieldwork, the Global Warehouse and the retail level shared the costs for the truck routes from and to the points of distribution. However, cores and remanufactured engines represented a very small amount of the total logistics costs.

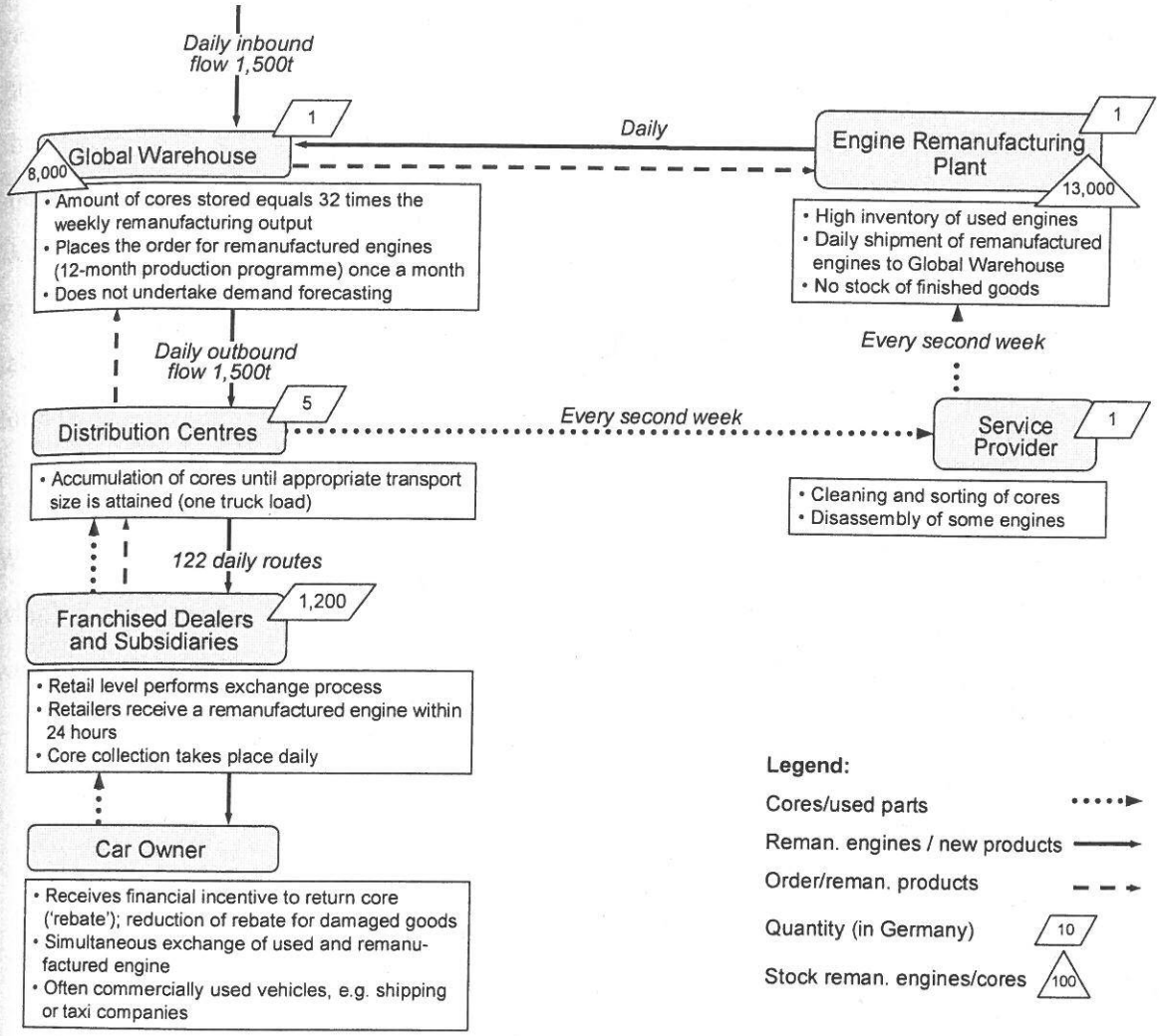


Figure 15: Core Collection, Product Distribution and Order Flows in OEM Engine Remanufacturing (Exchange Process) [34]

Within Case Company A, the process of (engine) exchange took place as follows. Subsidiaries and franchised dealers removed the worn-out engine from the car, which was collected by the (daily) route to the distribution centre. Distribution centres accumulated cores until an appropriate transport size was attained and subsequently sent the engines to a service provider (at least every two weeks). The Case Company outsourced, at the time of research, the core disassembly and cleaning process. As a

[34] All engine cores used to be disassembled and cleaned within the facilities of the remanufacturing plant. However, the management of the plant had decided to outsource these processes. Hence, at the time of the research (June 2002) there was a transition period in which the remanufacturer and the service provider

result, few of the engine cores were disassembled, cleaned and sorted by the service provider, the remaining by the remanufacturer. The service provider cleaned and sorted the engines and transferred the requested engines to the remanufacturing plant. In the meantime, the customer had received a remanufactured engine from stock (Global Warehouse) via one of the distribution centres. If the requested remanufactured engine was not on stock, it had to be remanufactured as quickly as possible. This may have taken between 4.5 and 5 days for a commercial vehicle engine and at least three weeks for a passenger car engine.

With regard to financial flows, the retail levels initially 'paid' the rebate to the customer, which was refunded by the vehicle manufacturer afterwards. In other words, the rebate was offset against the price of a remanufactured engine.

> *The retailers advance the rebate for our company. However, we refund the rebate at the time of the core's return to the distribution centre (refund in weekly intervals). The retailers only pay for the remanufactured engine in the next bill. Hence, in some cases they even don't have to advance the rebate. Overall, in between business segments and within our corporation, we totally ignore the rebate. In other words, in our accounting system, the rebate is not considered for exchanges between the Global Warehouse and the remanufacturing plant. Exchanges of goods between business segments are simply registered as changes in inventory within a central account.*[35]

System loss of cores occurred if a car owner did not approach a franchised dealer or a subsidiary, but decided to purchase a remanufactured engine from an independent garage. Company A had chosen not to take any countermeasures against the loss of cores, but sought to provide rebates above market price in order to ensure the backflow of engines to the remanufacturing plant. However, one interviewee explained that "no one can imagine that the owners of our luxury brand cars would purchase remanufactured engines from an independent garage. Company A's products are of superior quality". Another interviewee further added that there is no warranty on

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shared the disassembly and cleaning processes. The above graph, however, shows the state of the supply chain after the transition process.

[35] Quoted from personal communication (E-Mail) with the Manager for Reverse Logistics, Quality and Process Management at Case Company A's Global Warehouse, January 2004, translated from German.

remanufactured engines from independent garages. Therefore customers automatically approach a franchised dealer or a subsidiary. However, it has to be noted that also independent remanufacturers, such as VEGE-Motoren B.V. (2002) provide twelve months of warranty for their engines – with no mileage limitation. In addition, the break-up of 'traditional' retail structures, as outlined in Chapter Five, may lead to an increasing number of car owners approaching independent services, also for engine replacement. It may therefore be concluded that Company A was, to a certain extent, underestimating competition from the independent sector.

6.3 The Remanufacturing Plant

The remanufacturing plant was located in Germany, next to a new engine manufacturing plant. The plant merely recovered engines from the vehicle manufacturer's own luxury brand. In other words, no engine remanufacturing was undertaken for other industry players or on products manufactured by others. At the time of the research, the plant comprised between 350 and 400 employees.

6.3.1 Product Range

In 2001, fifty percent of the remanufacturing plant's capacity was taken up by 'exchange business', as defined in Section 6.2.1. With 38% of the capacity, the plant produced so-called 'manufactory engines'. This particular product group comprised engines for niche markets (e.g. colza engines), low-volume engine models which were assembled from new parts, discontinued engine models which were assembled from new parts and new engines with a high amount of variants for a very small volume. With the remainder of the capacity the production plant remanufactured water pumps (7%) and provided services to other centres within the group (5%; figures from 2001). However, in this research, the emphasis was put on the engine remanufacturing business of the plant.

Customers could choose between complete engines (on the variant level) and so-called 'basic engines'. Basic engines were defined as engines on which attached parts and

components, as for instance oil filter, water pump, injection pump, were omitted (long bloc engine). A short bloc engine was characterised as a basic engine without the cylinder head(s). At Company A, short blocs were exclusively manufactured from new parts.

Engines were classified into three groups. The first group comprised engines with a remanufacturing volume of 20 or more engines per month. The second classification included engine models with a production volume of at least 3 engines per month or 10 annually. The third group included all engines in between these first two groups. In this thesis, the classification which Parnaby (1988) has applied to a different scenario will be used for engine remanufacturing. The author therefore differentiates between 'regular runners', 'irregular runners' and 'strangers'.

- Regular runners => remanufacturing volume of 20 or more engines per month
- Irregular runners => remanufacturing volume of 10 to 20 engines per month
- Strangers => remanufacturing volume of 3 to 10 engines per month

In 2001, eight regular runner engine variants of three different engine models fulfilled 32.4% of the orders placed by the Global Warehouse. With additional eight engine variants, a total of 41.9% of the customer's orders were accomplished. Further 397 engine variants were required to satisfy customer orders to 100%. This means that with just 16 engine variants, more than one-third of the customer's orders were fulfilled. These figures also indicate that 397 engine variants were produced in volumes of three to 20 per month.

The remanufacturing process itself was based on an engine number classification. Therefore, figures displayed in this chapter are based on engine numbers, but mostly on the engine model classification, which differentiates between different fuel types. This research therefore generalises within engine models, since several hundreds of engine variants and sub-variants hide behind one engine model. However, data interpretation was challenging since limited information on the individual engine models was available.

6.3.2 Production Volumes

Between 1986 and 2001, Case Company A had remanufactured a total of 232,809 (excluding engines for classic cars and basic engines) at the remanufacturing plant, whereof the majority (75.7%) comprised diesel engines.

The following Table 38 displays Company A's remanufacturing output from 1986 to 2001[36]. In 2001, for example, around 250 engines were remanufactured per week. Compared to these figures, Ivor Searle, the biggest independent remanufacturer of engines and engine components in the UK, remanufactures 70 to 100 engines in a typical week (with 700 to 800 held in stock) (see Phillips, 2001). Hence, the independent remanufacturer keeps the tenfold amount of a weekly remanufacturing output on stock. With regard to the Case Company, the author observed the first inefficiency in the form of high stock levels, since Company A stored 8,000 remanufactured engines at the Global Warehouse. This equals 32 times the weekly production output of the remanufacturing plant.

[36] Due to the company's request for anonymity, the names of engine models were falsified. Petrol engines were numbered from P1 to P16 and diesel engines from D1 to D14. Since the anonymisation of engine model numbers was undertaken in accordance with the consecutive numbers of the engines, the following table does not include the models P14, P15 and D13.

Engine	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
P1	-	-	8	9	-	13	-	-	-	-	-	-	-	-	-	-	30
P2	-	1,605	6,678	8,088	3,641	4,229	2,882	2,014	1,117	1,043	687	531	331	114	81	25	33,066
P3	-	321	1,172	2,156	1,613	1,680	1,604	871	486	448	309	123	70	64	21	20	10,958
P4	-	-	-	-	-	30	90	191	187	131	111	158	39	-	-	-	937
P5	-	685	1,602	1,029	690	340	285	170	30	9	5	24	15	5	-	-	4,889
P6	-	-	-	-	-	-	-	-	229	137	265	265	120	60	-	-	1,076
P7	-	-	-	-	-	-	-	-	-	-	-	-	29	133	155	623	940
P8	-	-	-	-	-	-	-	-	-	-	-	-	-	6	10	164	180
P9	-	285	341	130	175	200	130	105	28	16	12	20	10	5	-	-	1,457
P10	-	25	97	116	116	125	128	80	50	20	30	10	10	-	-	-	807
P11	-	10	139	150	100	100	100	80	24	19	26	10	20	9	-	-	787
P12	-	-	-	-	-	-	30	140	176	80	62	65	29	3	-	-	585
P13	-	-	-	-	-	-	-	56	126	96	28	20	95	38	26	34	519
P16	-	-	-	-	-	-	-	-	-	-	-	-	-	20	125	216	361
D1	-	115	299	595	666	1,022	1,509	1,687	2,974	4,641	2,952	3,610	3,611	4,770	3,345	1,647	33,443
D2	-	75	150	140	315	1,037	1,611	2,485	4,279	5,079	3,762	4,291	5,529	7,337	5,190	3,363	44,643
D3	-	65	156	115	276	471	970	1,299	1,677	2,585	1,949	885	799	393	327	189	12,156
D4	-	-	-	-	-	-	-	-	-	56	228	303	290	184	198	101	1,360
D5	-	-	-	-	-	-	-	-	-	137	346	362	204	204	303	132	1,688
D6	-	-	-	-	-	-	-	-	-	46	97	132	229	213	213	173	1,103
D7	-	-	-	-	-	-	-	-	-	-	-	-	-	378	1,751	2,626	4,755
D8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149	561	710
D9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	126	234	360
D10	80	1,780	1,276	965	1,266	770	415	240	119	160	67	144	60	-	-	-	7,342
D11	10	6,200	6,419	6,770	7,807	6,260	4,032	2,524	3,057	2,609	2,261	1,017	1,041	793	532	237	51,569
D12	10	1,465	1,568	2,080	3,040	1,781	1,280	873	908	577	992	635	454	276	222	118	16,279
D14	-	-	-	-	-	-	-	-	-	-	-	-	-	43	343	423	809
Classic	-	20	213	145	94	105	63	7	30	26	6	-	-	-	-	-	709
Basic	-	-	-	270	12	410	493	80	363	394	562	1,280	1,607	2,515	2,210	2,054	12,250
Total	**100**	**12,651**	**20,118**	**22,758**	**19,811**	**18,573**	**15,622**	**12,902**	**15,860**	**18,309**	**14,757**	**13,885**	**14,592**	**17,563**	**15,327**	**12,940**	**245,768**

Table 38: Annual Remanufacturing Output from 1986 to 2001 (Source: documentation and interviews – Case Company A)

6.4 The Remanufacturing Process

As Chapter Five has pointed out, the remanufacturing process consists of several phases. This section discusses the specific engine remanufacturing process, as it was observed within the OEM remanufacturing plant in 2002. Chapter Five has also outlined the manufacturing operation of new engines. Machining of parts within an engine manufacturing operation is generally fully automated and characterised by high volume outputs, whereas the assembly of a new engine is less automated. Engine remanufacturing, on the other hand, is largely manual throughout the process.

Figure 16 shows a typical engine remanufacturing process, as it was observed in Company A. The in-plant processes, which will be discussed in the following, only comprise processes undertaken within Company A's remanufacturing plant. However, some engine parts were remanufactured by external and internal service providers, yet these remanufacturing processes were not considered within this research.

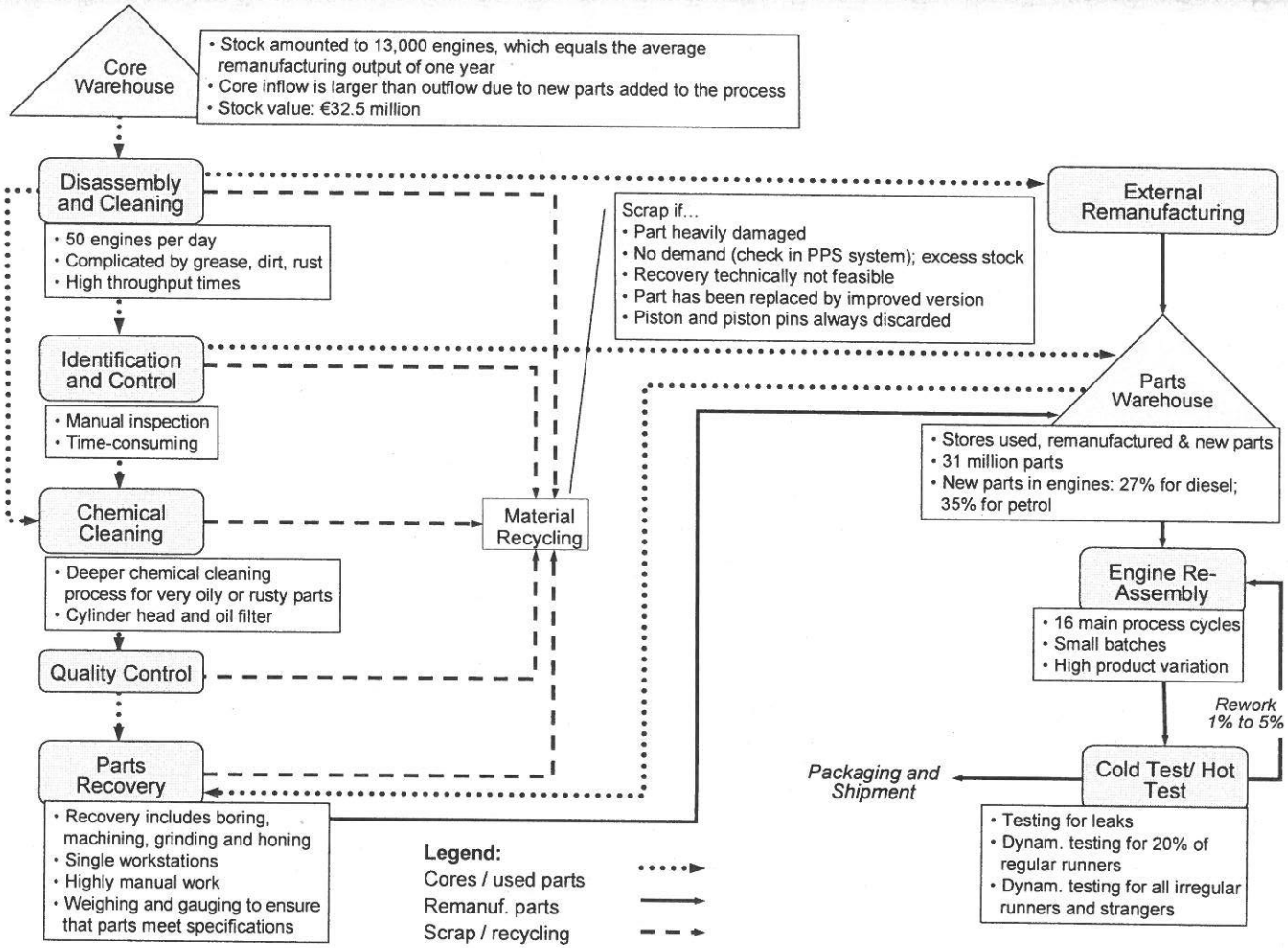


Figure 16: Typical Engine Remanufacturing Process

(Source: adapted from Seitz and Peattie, 2004, p.79)

6.4.1 In-Plant Remanufacturing Process and Material Flows

This section discusses the process steps of Figure 16 in more detail.

Core Delivery and Storage

At the time of the research, incoming cores were stored in an open-air warehouse next to the remanufacturing facilities. Approximately 13,000 used engines lay on stock. Comparing this figure to Table 38 in the previous section, the data shows that in 2002, the Case Company stored an amount of cores which was equal to the annual remanufacturing output in 2001. Based on incoming orders from the Global Warehouse, engines were dismantled and parts remanufactured.

Overall, the return flow of cores was larger than the amount of engines which were used in production (as shown in Table 39). This may have been influenced by new parts that were added to the remanufacturing process or by a mismatch between the supply of cores and demand for remanufactured engines. A further reason for a higher inflow than outflow of engines has been outlined by Steinhilper (1998), who explains that when a new car model is introduced to the market, there are none or very few cores available in the initial phase. Prices for cores are therefore high. One of the Case Company's practices was the assembly of 'remanufactured' engines from new parts in this initial phase, so to 'start off' the process and to meet demand. This may have led to an overhang of cores returning later in the remanufacturing life cycle.

Steinhilper (1998) further explains that as soon as there are more cars on the roads, core availability increases and market prices for cores decrease. In this life cycle phase, Company A turned to cores as the main source of raw material. However, at the end of a car model's market cycle, more cores seem to be available, but demand for remanufactured products decreases (Steinhilper, 1998). This is not true for classic or vintage car engines, for which there still may be demand.

> *First, demands for an engine class follow the shape of a product life cycle, starting with a phase of increasing sales, followed by the maturing phase and finally declining sales towards the end of a product's life cycle. Returns follow demands in a similar pattern, delayed by the usual lifetime of an engine and reduced by the fact that not all engines are returned. In the growing phase, demand for remanufactured engines is significantly higher than available returns and all returned cores are remanufactured. Later, in the maturing phase, demand decreases and returns can exceed remanufacturing orders.*
>
> (Kiesmüller *et al.*, 2003, p. 222)

In 2001, around 5,000 engines were scrapped, since the warehouse reached the maximum inventory level. According to Sherwood and Shu (2000), overstock is the second most scrap mode for OEM remanufacturers. "When parts can be bought more cheaply than they can be refurbished, old parts are scrapped. Parts are also discarded when there is sufficient inventory and no more storage capacity" (Sherwood and Shu, 2000, p.89). Table 39 displays inventory level increases and decreases in 2001.

Month	Increase of Cores	Decrease of Cores
January	1575	1021
February	1225	955
March	1384	1258
April	1044	823
May	1084	847
June	795	886
July	1540	966
August	1260	690
September	1016	836
October	1226	639
Total	**12,149**	**8,921**

Table 39: Core Warehouse Increases and Decreases in 2001
(Source: documentation and interviews – Case Company A)[37]

For the company, the core warehouse signified a large amount of capital bound in stock. At the time of the research, the warehouse manager estimated an average engine core

[37] In August, September and October 2001, fewer engine cores were disassembled, since two employees were transferred from the disassembly to the re-assembly process.

value of €2,500 each. As a result, €32.5 million were bound in engine cores. However, this figure did not include costs like salaries or rent. Further costs involved €130,000 for warehouse personnel (including costs for the parts warehouse), €70,000 for rent and operating costs of €4,000 (in 2001). Company A was aware that the management of these cores needed to become more efficient and began preparations for the outsourcing of the core warehouse management in 2002.

The manager of the core warehouse explained in the interview that two aspects had contributed to difficulties within core management. Firstly, the Global Warehouse, the remanufacturing plant's 'customer' possessed all engine cores. Consequently, all decisions had to be approved by executives of the Global Warehouse. This also included a potential scrapping of excess stock.

Secondly, the warehouse manager noted that there was a rather 'chaotic' approach to core storage management. Engines of different qualities or age were stored next and above each other. As a result, it took employees a significant amount of time to locate the right engines for the disassembly process.

Disassembly, Cleaning and Identification Processes

In this specific remanufacturing plant, disassembly took place at ten single workstations. Initially, approximately 50 engines were dismantled every day. However, since the management of the remanufacturing plant had decided to outsource the disassembly process, just around 25 cores were disassembled at the time of the fieldwork (2002). The remaining 25 engines were disassembled by an external service provider.

According to Steinhilper (1998) 534 single operations are necessary for the complete disassembly of an automotive engine. In his view, the majority of joinings can be loosened in easy steps. However, grease, dirt or rust may constrict the disassembly process.

Within Company A, disassembly process throughput times were high. One worker required between 127 and 147 minutes for one in-line diesel engine with one camshaft.

Dismantling of five-cylinder engines took about 160 minutes and 170 minutes for six-cylinder diesel engines. Up to three hours were required for a V-12 engine. For each engine model, specific disassembly equipment was provided. Due to the large amount of engine variants, workers were skilled in order to avoid damage to parts and components.

At Company A, parts were cleaned after disassembly. The cleaning process was divided into two parts. Some components were cleaned with water and detergents first and thereafter sent to the identification process. No further cleaning was necessary here. Other parts, such as the cylinder head or the oil filter, underwent a deeper chemical cleaning process before they were inspected for damages. Also, more complex components were cleaned first, thereafter completely disassembled. Damaged and unusable parts were collected for materials recycling. Pistons, piston pins and connecting-rod bushes were always discarded. Similar practices have been reported by independent engine remanufacturers, such as VEGE-Motoren B.V. (2002), who replace pistons, main bearings, connecting rod bearings, valves (if necessary), valve seats, timing belts, as well as chains and gaskets by new parts. Within Company A, the proportion of new parts in a reworked engine lay between 27% for diesel and 35% for petrol engines. Overall, the case remanufacturer anticipated an average scrap quota of 20%.

The cleaning process was followed by the identification and quality control process. The identification process was essential to stock-keeping. Parts and components were manually inspected and sorted by part numbers. Again, workers were skilled, since there was a high diversity of parts. Workers compared specifications and product characteristics with the requirements on specification sheets. Moreover, they applied gauging, measuring, and visual checks in order to specify parts. According to Phillips (2001) potential quality inspection for valves may include the measuring of 'head thickness' and 'stem wear'. Valve springs may be examined with regard to 'squareness', height and compressed load length, for example.

Steinhilper (1998) explains that during parts identification, parts may be classified into three categories. Firstly, parts which may be re-used without recovery. At Company A, this rarely occurred. This led to the assumption that the Case Company underwent a

'standardised' product recovery programme, even though it may not have seemed necessary.

The second product classification within the identification and control process is 'remanufacturable', which includes parts that may be restored to an 'as good as new' condition. The last product group includes parts with severe damages, which are scrapped. The reasons for scrapping may vary and have been extensively outlined by Sherwood and Shu (2000). Scrap rates within Company A will be further discussed later in this chapter. Within the Case Company, damaged and unusable parts were collected for materials recycling.[38]

The Recovery Process

Remanufacturing processes for parts were different for individual types of parts. The following remanufacturing activities may have taken place (see also Steinhilper, 1998).

- Boring of cylinder head
- Grinding of crankshaft, camshaft and various surfaces
- Turning of connecting rods and crankshafts
- Honing of cylinders

To narrow down the scope of the study, the remanufacturing processes of the five important engine parts, camshaft, crankshaft, connecting rods, cylinder head, and cylinder block, were observed. Parts' remanufacturing took place at single workstations or within machines and included honing, lapping and machining processes. As opposed to the machining processes within the manufacturing of new engines, a large number of these activities were carried out manually or supported by manual labour.

[38] Company A assumed that, at the time of the research, around 72% of an average engine could be effectively used in the recovery process. 26% of an engine were recycled, including grey iron, aluminium and mixed iron. Just 2% of a core had to be discarded. However, the company neglected to account for these figures in more detail. For example, it was not clear if these percentages referred to the weight of an engine or the number of parts.

Within cylinder block remanufacturing, the cylinder sleeves (liners) of the crankcase were 'pressed out' and replaced by new liners, since the wear of an engine is most significant in the cylinders. Engine blocks without liners were 'over-bored'. These engines may have received oversize pistons or new cylinder liners and standard pistons in the process. Cylinder blocks underwent a leakage-test. Tests at this stage sought to anticipate expensive recovery processes with damaged or unusable parts.

The cylinder head underwent a leak-test, too, whereas the remanufacturing processes of this part included surface machining. Cylinder head remanufacturing comprised the reworking of valve seats and the replacement of valve guides. Furthermore, oil ways were re-bored and bearing points lapped. The final inspection with a pneumatic gauge ensured that bearing shells matched the crankshaft, a process which is also known in the manufacturing of new engines

The remanufacturing of camshafts, crankshafts and connecting rods mainly comprised grinding of the main bearing, as well as the big end bearing of the crankshaft, in order to eliminate damages caused by wear. Sherwood and Shu (2000) explain that by eliminating worn external surface material, the diameters of parts are reduced. As noted above, cylinder boring resulted in larger cylinders and therefore required oversize pistons. Similarly, oversize bearing shells for crankshafts and camshafts were required after grinding. The remanufacturing of these parts also comprised weighing and gauging to ensure that parts met the specifications.

Overall, there were two obstacles within these processes. Firstly, many of these activities were time-consuming and had to be accomplished manually. Moreover, machining equipment was used for more than one engine part. The machining process for camshafts and crankshafts, for example, took place in the same grinding machine. Tool changing times lay between 90 minutes and one day and therefore had to be planned carefully.

Re-Assembly

After parts recovery, all parts, with the exception of the cylinder block, were put on stock. In other words, the remanufacturer took a 'recovery-to-stock' approach, whereas engines were re-assembled according to the customer's order ('assemble-to-order').

Re-assembly of the engines took place at a short assembly line with around 16 main work cycles. These cycles strongly resembled those of new engine assembly, with the only distinction that work cycles tended to be significantly longer. A single worker may have spent up to 10 minutes for one cycle. Workers were also responsible for the pre-assembly of engine components, such as the pre-assembly of pistons and connecting rods. Again, in the re-assembly process, workers were skilled, since batch sizes were small and therefore different engine models were assembled within one shift. Overall, the author perceived the re-assembly of remanufactured engines as less pressurised for a worker, compared to a high-volume engine assembly process. At the time of the research, the average re-assembly throughput time was 490 minutes for a regular runner engine. This also included non-manual work cycles, such as the cold test.

Cold and Hot Test

During a hot test, an engine is tested for performance and leaks, whereby the engine runs with own power until a specific oil temperature is achieved (JW Fröhlich Maschinenfabrik GmbH, 2003). In 'conventional' high-volume engine assembly plants, the hot test is standard. Alternatively to the hot test, a cold test may be undertaken in combination with a dry air leak test. Within the cold test, the engine is not fired. In comparison to the hot test, a reduced test time is achieved, less investment necessary and environmental pollution is reduced (JW Fröhlich Maschinenfabrik GmbH, 2003). However, an additional leak test is required alongside the cold test. Generally, the dry air leak test is an essential part of final engine testing. It is performed before the engine is filled with oil.

Within the Case Company, all remanufactured engines underwent a cold test. In addition to the cold test, 20% of the regular runner diesel engines were tested on a dynamometer for approximately 20 minutes (hot test). All other engine models

(irregular runners and strangers) were hot-tested. About one to five percent of the remanufactured engines failed the tests and had to be reworked.

6.4.2 Detailed Process Observation

This section examines the remanufacturing process of passenger car engines in more detail. The remanufacturing throughput times for the main process steps within remanufacturing are presented. The data was obtained from company reports and documentation, but had been verified in interviews with the person in charge. The aim of the section is to outline the uncertainty and variability within individual process steps of a remanufacturing operation. The section demonstrates that process times for activities, such as disassembly and cleaning, may vary, depending on the engine model. Moreover, the condition of the engine (rust, dirt, oil) may complicate certain processes.

Production Programme Planning

Within the Case Company, the planning of the remanufacturing program was based on the orders placed by the Global Warehouse. In monthly intervals, the Case Company received a 12-month production programme (order), which comprised a list of the requested engine variants and their quantity. These orders could not be changed for the succeeding three months. However, for every subsequent month, modifications within the order could have been made by the Global Warehouse.

Six weeks ahead of production, the remanufacturer began with the preparations. A monthly order usually comprised 1,000 engines. There was a general lack of computer system support for remanufacturing. The orders were put into a spreadsheet format and engines were brought into a production sequence manually (without computer system support). One production programme planner allocated the production volumes and engine types onto four re-assembly lines. The planner also entered the engine parts lists into a PPS System, so that further planners and schedulers were able to begin the procurement of parts. At the same time, the dismantling of cores began. The amount of cores that were dismantled was influenced by capacity constraints. However, it was

equal the amount of engines required in the re-assembly process plus the expected scrap rate. The PPS System calculated the material requirements and the planners were responsible for providing the exact amount of parts at a specific date. If parts could not be remanufactured on time, new parts were added to the process.

Throughput Times for Disassembly and Cleaning

As already pointed out by Goggin *et al.* (2000), product recovery tends to be labour intensive. The disassembly and cleaning process, an activity that cannot be found in a high-volume engine manufacturing plant, was characterised by high throughput times within Company A. The research has found that within automotive engine remanufacturing, throughput times for dismantling strongly depended on the engine model. Workers on the shop floor claimed that a four- or five-cylinder engine could be disassembled in 60 minutes. However, the dismantling of a V-12 engine took up to three hours. These throughput times were estimated by workers and their foreman. However, Company A asked an independent service provider to measure throughput times for all process steps in order to establish targets with regard to process times. Table 40 shows these times (in minutes), which include disassembly and cleaning activities.

Throughput times in this section included the complete disassembly of all components, as well as cleaning activities rather than just the engine dismantling time. In the case of diesel engines, the time for complete engine disassembly and cleaning of parts varied between 127 and 147 minutes for in-line engines with one camshaft. For a five-cylinder engine, one worker required between 160 and 170 minutes for six-cylinder diesel engines.

Step	Activity	4-Cylinder Diesel	5-Cylinder Diesel	5-Cylinder Turbo-Diesel
1	Preparing engine	6.24	6.24	6.24
2	Dismantling	75.26	86.38	116.02
4	Hydrodynamic works	1.00	1.00	1.04
5	Removing oil channel plugs	1.11	1.11	1.11
6	Bearing support dismantling	0.46	0.46	0.46
7	Cylinder head dismantling	4.10	4.47	4.47
8	Pistons/connecting-rods dismantling	3.14	4.04	4.04
9	Pre-soaking of parts	5.02	6.04	6.04
10	Washing cylinder head	2.03	0.43	0.43
11	Washing parts	8.06	10.37	10.37
12	Cylinder head grinding	4.14	4.34	4.34
13	Oil filter dismantling	2.43	2.43	2.43
14	Oil pump dismantling	1.29	1.29	1.29
15	Sorting	9.00	10.20	10.20
16	Preserving parts in oil	2.40	2.40	2.40
17	Diverse finishing activities	0.27	0.27	0.27
	Total	**127.55**	**144.27**	**173.55**

Table 40: Lead Times within the Dismantling Processes in 2002 (in minutes; rounded) (Source: documentation and interviews – Case Company A)

Throughput Times for Chemical Cleaning, Identification and Control

Oily or rusty parts, such as the cylinder head underwent a special cleaning processes, such as a chemical wash with petroleum, sandblasting or the soaking in an acid bath, before they could be assessed for their recoverability. The cleaning process was very time-consuming. Parts spent up to four hours in the acid bath. The second inspection of the parts after cleaning took about 10 minutes and an additional 16 minutes for the identification of each part.

Engine	Quantity	Parts Recovery	Honing and Completion	∑
P1	-	-	-	-
P2	69	58.16	31.50	90.06
P3	101	62.28	34.16	96.44
P4	88	74.11	34.16	108.27
P5	-	-	-	-
P6	182	83.13	20.58	104.11
P7	283	-	14.41	-
P8	69	-	15.00	-
P9	-	-	-	-
P10	38	107.50	96.12	204.02
P11	7	108.40	96.56	205.36
P12	57	101.58	90.58	192.56
P13	13	123.41	110.18	233.59
P14	-	-	-	-
P16	101	-	13.14	-
D1	1,810	54.47	29.09	83.56
D2	3,377	57.28	29.09	86.37
D3	337	64.31	29.04	93.35
D4	198	55.52	27.39	83.31
D5	89	57.28	27.46	85.14
D6	123	64.34	29.25	93.59
D7	3,126	-	10.41	-
D8	756	-	11.21	-
D9	250	-	11.06	-
D10	-	-	-	-
D11	317	41.41	28.33	70.14
D12	77	45.39	36.07	81.46
D13	-	-	-	-
D14	509	-	7.42	-
Total	**11,977**			

Table 41: Recovery Throughput Times Cylinder Block in 2001 (in minutes; rounded) (Source: documentation and interviews – Case Company A)

With regard to remanufacturing throughput times, there are significant differences between engine models. Table 41 summarises recovery times (in minutes) for cylinder blocks in 2001, as far as these were available within the Case Company.

The recovery process took between 40 and about 70 minutes for a cylinder block of an in-line engine. As described earlier in this chapter, parts recovery included activities,

such as the replacement of cylinder liners or the boring of cylinders. The honing and completion processes (e.g. leakage test) took between 15 and 36 minutes for in-line engines. Throughput times were higher for V-engines, such as the engines P10 to P13.

Re-Assembly and Hot-Test

As outlined in Chapter Six, the re-assembly process was similar to the engine assembly process in a conventional engine remanufacturing plant. On the assembly line for regular runner engines, it took about 490 minutes (from start to finish) to re-assemble an average remanufactured engine with four or five cylinders. Thereafter followed the hot test for most of the engines (20 minutes).

Summary of Lead Times

The following figure summarises the average recovery lead time for one in-line four- or five-cylinder engine. For parts recovery and chemical cleaning the lead time for an average cylinder block was put into the graph, since the company assumed that this part required the longest lead times of all parts to be recovered. Overall, the pure remanufacturing lead time for one engine is therefore 16 hours and 43 minutes for a four-cylinder and 17 hours and 18 minutes for a five-cylinder engine.

The company itself was unaware of the overall remanufacturing lead times. Hence, this summary was the first attempt to calculate an estimate of how long it took to recover an average four- or five cylinder engine without parts being put on stock. However, in order to identify the 'waste of inventory', for example, it would have been necessary to include storage times and transportation times between the different locations, too. Unfortunately, these were not available at the Case Company, due to high parts variability, process complexity and limited labour time. As a result, the absence of storage times in the calculations is also a drawback of the account in Figure 17.

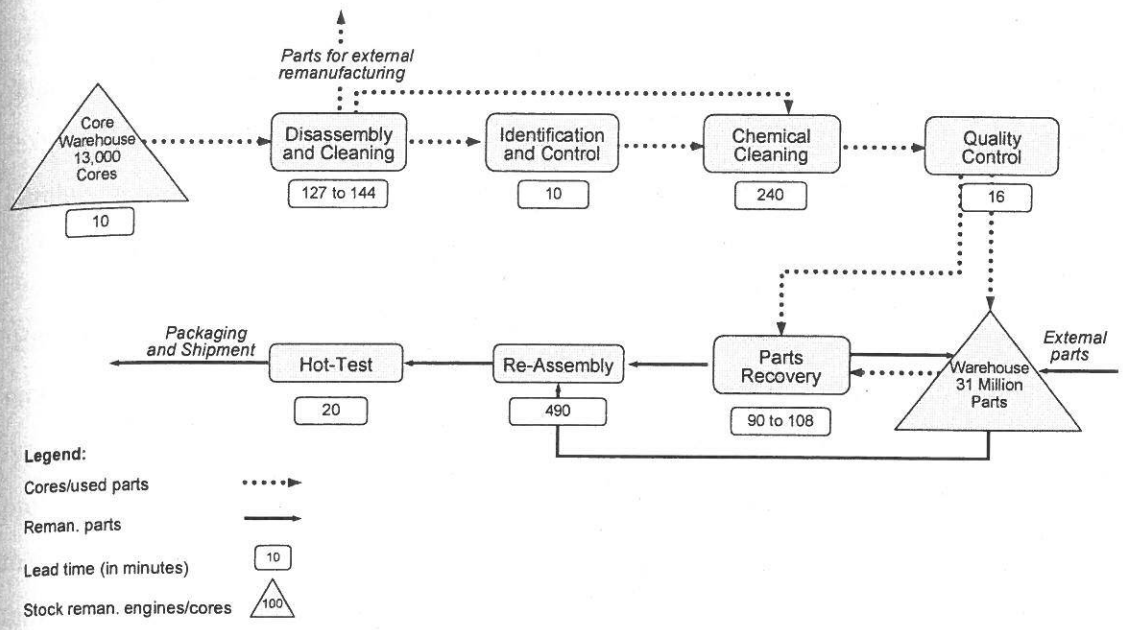


Figure 17: Lead Times Summary for Remanufacturing in 2001 (in minutes) (Source: documentation and interviews – Case Company A)

6.4.3 Major Issues Identified within Engine Remanufacturing

It may be assumed that Company A's remanufacturing plant is among the largest in the European remanufacturing sector. However, compared to (smaller) independent remanufacturers, who may apply a remanufacture-to-order approach with short order fulfilment and delivery times. Company A's plant manager claimed that, at the time of the research, delivery times for remanufactured engines were 20 working days on average for a regular runner engine, an average of 40 working days for a irregular runner and 50 days for a 'stranger' (in 2002). This section discusses aspects, which may have influenced the long order fulfilment process, such as the long delivery times for external parts, high scrap rates, small batch sizes, product variation and the problem of forecasting demand.

Delivery Times for Parts

One of the factors which had an impact on engine order fulfilment was the long delivery time for parts which were procured externally. As previously noted, just 30% of the

parts were remanufactured within Company A's plant. As a result, the case remanufacturer procured more than two thirds of the engine parts externally: new parts, 'external' and 'internal' parts. New parts, such as pistons and bearing shells, were purchased from serial suppliers.

'External' components comprised all parts, which were either remanufactured or procured by external service providers. External hereby referred to all companies, which were not a part of Vehicle Manufacturer A. Internal services, on the other hand, were provided by other business sectors within the group. These internal service providers may have remanufactured or produced the part. As an example, pneumatic pumps were remanufactured by another member of the group. Oil sumps, on the other hand, were manufactured (new) by another company within the group.

Table 28 illustrates the delivery times for external and internal services, as well as the delivery time for supplied services on the premise of a worst case (longest delivery time) and at the time of the research. In the case of multiple sourcing of parts, the table shows the longest delivery time. These long delivery times resulted in high inventory levels to avoid bottlenecks in parts supply.

External Components (remanufactured or new, depending on availability)												
Part	**Delivery Time in Weeks**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Generators												
Valves												
Exhaust-driven turbocharger												
Injectors												
Nozzle holders												
Injection pump												
High-pressure pump												

Internal Services (remanufactured or new, depending on availability)												
Part	**Delivery Time in Weeks**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Injection line, bolts, fuel injection pump, holder etc.												
Chain adjuster												
Water pump housing												
Pneumatic pump												
Water pump flange, impella, drive wheel												
Oil sump	**up to 26 weeks**											
Cap nut												
Cylinder head caps												
Cylinder heads and crankshafts												
Bearing support												

New Parts (always new)												
Part	**Delivery Time in Weeks**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cylinder liners												
Pistons												
Bearing bushes/bearing shells	**4 to 14 Weeks**											
Cylinder head seals												
Seals												

Table 42: Delivery Times for Parts used within Re-Assembly in 2002
(Source: Vorst, 2002; documentation and interviews – Case Company A)

Similar difficulties within parts procurement for remanufacturing were observed by the production scheduler of a UK-based engine remanufacturing plant (Case Four, as shown in Figure 10 in Section 4.3.2), which was subcontracted to a major vehicle manufacturer. The managing director stated in the interview that his company also had difficulties to acquire spare parts in the right quantities and on time, since 'the line

comes first'. In other words, vehicle manufacturers request that their suppliers give priority to the assembly line for brand-new engines. It therefore seems as if remanufacturers only come at second place in the 'order fulfilment hierarchy'. Moreover, remanufacturing plants tend to order small quantities and suppliers may give priority to high-volume orders.

Scrap Rates

Sherwood and Shu (2000) differentiate between 'failure mode', the nature of the failure, and 'scrap mode', the cause for part to not being recovered. According to these authors, within engine remanufacturing there are different failure modes, including 'wear', 'burn', 'bent', 'crack', 'corrosion', 'holes', 'fracture' and 'handling damage'. Scrap modes include the over-or undersize of parts or simply overstock (Sherwood and Shu, 2000).

The research findings of Sherwood and Shu (2000) include that 'wear and tear' is the most common description of product failure and undersize and oversize of parts is the most likely cause for scrapping among independent and OEM remanufacturers. Oversizes and undersizes occur if parts have been previously remanufactured or wear patterns are so significant that the part cannot be remanufactured without becoming an over- or undersized part. Moreover, certain parts that wear together must be incorporated into the same (remanufactured) engine (e.g. connecting rods). In this case, scrap occurs if one part is missing, broken or parts have been mismatched.

In this research, no particular emphasis was put on the identification of failure and scrap modes for certain parts, but on scrap rates in general. It was found that cores did not represent a very reliable source of 'raw material', since the time of return and quality of the parts and components were unclear. Within Company A, high scrap rates were observed within all processes, but particular within disassembly and recovery. Table 43 gives an example of cylinder block scrap rates in 2001. Appendices H and I shows further figures for cylinder heads and crankshafts.

Engine Model	Total Number of Cylinder Blocks	Usable Parts	Scrap in Figures	Scrap in %
P2	272	160	112	41.2
P3	207	160	47	22.7
P4	239	206	33	13.8
P6	473	391	82	17.3
P7	331	251	80	24.2
P8	73	56	17	23.3
P9	7	6	1	14.3
P10	93	75	18	19.35
P11	22	13	9	40.9
P12	179	123	56	31.3
P13	48	40	8	16.7
P16	210	173	37	17.6
D1	2,986	2,569	417	14.0
D2	5,254	4,376	878	16.7
D3	599	453	146	24.4
D4	220	205	15	6.8
D5	271	227	44	16.23
D6	260	224	36	13.8
D7	1,572	1,465	107	6.8
D8	236	207	29	12.3
D9	113	105	8	7.1
D11	440	387	53	12.0
D12	183	168	15	8.2
D14	261	237	24	9.2
Total	**14,549**	**12,277**	**2,272**	**15.61**

Table 43: Scrap Rates for Cylinder Blocks – January to December 2001
(Source: documentation and interviews – Case Company A)

Cylinder head scrap rates were assumed to be high (see Appendix H). According to one interviewee at the plant, this was due to the complexity of the part itself. Furthermore, cylinder heads were difficult to process (machine). Overall, cylinder heads are the most highly stressed parts of an engine and are therefore prone to damage.

Product Variation

Chapter Five has already pointed out the difficulties of managing product variety in a remanufacturing environment. This section discusses the situation at the Case Company, as it was observed during the fieldwork. Within Case Company A, the serial production of a car model lasts between six and ten years. In this period engines are continuously upgraded due to cases in which manufacturing, construction and design errors are eliminated or new technologies are implemented. Technological changes lead to further engine variants. External constraints, such as governmental regulations (exhaust norms), further increased the amount of engine variants in each model or type of engine.

Of all engines that Company A ever produced, the remanufacturing programme comprised 27 engine models, which equals 777 engine variants, in the year 2000. As the subsequent section will demonstrate, product variation has had an impact on batch sizes within the re-assembly process, but also on inventory management, as previous sections have shown. Similar observations have also been discussed in practitioner circles. One of America's largest core supplier, RAS, for example, sources 35,000 different part numbers and seems to find the management of the large investment more and more difficult to handle (Anonymous, 2003).

> *One of our strengths is that we're very good at sorting the cores, so it's easy for a rebuilder to buy from us. That's one of the secrets behind being a good core supplier – in fact it's the most important thing. We have also become better at buying the right parts in international markets, partly because we have well-trained buyers and partly because of careful planning. And then we are honest and pay promptly – the only way to get our customers to return.*
>
> (Niels Jensen, Purchasing Manager of a North American core supplier in Anonymous, 2003, p.8)

Within their research, Hammond *et al.* (1998) have assumed that original manufacturers would apply design metrics and specifications so as to complicate remanufacturing for 'outsiders'. The authors presumed that in this way, original manufacturers sought to exclude competitors from the remanufacturing activity. There were clear trends of 'parts proliferation', which is defined as "[...] the practice of making many variations of the

same product that differ only in one or two minor areas" by Hammond *et al.* (1998, p.31). This case study has shown that parts proliferation was as much an issue to the original manufacturer, as it seemed to be for independent players in the market. Within the Case Company, the increase in parts variety resulted in high inventory levels of cores, new parts as well as finished goods. Despite the fact that mass customisation is a common strategy in the automotive sector, and the platform strategy is also applied to the engine level (as outlined in Chapter Five), frequent car model updates or technical improvements of parts and components resulted in a large amount of product variants.

Re-Assembly Batch Sizes

The extent in the breadth and depth of the product range within engine remanufacturing also led to small batch sizes within Company A's engine re-assembly process. Table 44 displays batch sizes in the re-assembly process, as they occurred in 2001. It indicates the batch size and the quantity of that particular batch in 2001 (column 'number of times'). Moreover, the table shows the sum of engines which were produced with each particular batch size (column 'engines produced') and the share of the overall production volume in percent.

The re-assembly batch size of five accounted for 18.51% of all engines produced in 2001. Nearly 15% of these engines had been assembled in a batch size of ten. In comparison to that, the largest batch size of 225 occurred just once (one variant of engine model D2). The table has furthermore shown a clear accumulation of batches in steps of five.

Batch Size	Number of Times	% of Total Numbers	Engines Produced	% of Total Engines Produced
1	2	0.19	2	0.02
3	86	8.29	258	1.98
4	2	0.19	8	0.06
5	483	46.58	2,415	18.51
6	3	0.29	18	0.14
7	1	0.10	7	0.05
8	25	2.41	200	1.53
9	1	0.10	9	0.07
10	195	18.80	1,950	14.94
12	1	0.10	12	0.09
13	7	0.68	91	0.70
15	52	5.01	780	5.98
16	1	0.10	16	0.12
18	7	0.68	126	0.97
20	61	5.88	1,220	9.35
21	1	0.10	21	0.16
23	2	0.19	46	0.35
25	19	1.83	475	3.64
27	1	0.10	27	0.21
28	2	0.19	56	0.43
30	20	1.93	600	4.60
33	1	0.10	33	0.25
35	5	0.48	175	1.34
40	15	1.45	600	4.60
45	3	0.29	135	1.03
50	9	0.87	450	3.45
60	9	0.87	540	4.14
65	1	0.10	65	0.50
70	2	0.19	140	1.07
80	5	0.48	400	3.07
90	3	0.29	270	2.07
100	1	0.10	100	0.77
110	1	0.10	110	0.84
120	1	0.10	120	0.92
125	1	0.10	125	0.96
140	1	0.10	140	1.07
150	2	0.19	300	2.30
185	1	0.10	185	1.42
200	3	0.29	600	4.60
225	1	0.10	225	1.72
Total	**1,037**	**100**	**13,050**	**100**

Table 44: Re-Assembly Batch Sizes in 2001

(Source: documentation and interviews – Case Company A)[39]

[39] The overall remanufacturing output is slightly higher than indicated in Table 38, which is due to unofficial services to third parties.

Demand Forecasting

Chapter Two has already outlined the academic debates with regard to the uncertainties in product recovery management. A particular emphasis was thereby put on forecasting, such as tools for core acquisition (e.g. Toktay *et al.*, 2003b) and the management of supply and demand (e.g. Ferrer, 2001). Within the Case Company, no particular forecasting methods were applied. The departmental manager of aggregates and assemblies (including remanufactured passenger car engines) at the Global Warehouse stated in the interview, "we used to request a forecast from our two major customers, USA and Great Britain. These figures, however, never matched the subsequent orders and we therefore ceased to forecast future demand of remanufactured passenger car engines".

> *The durability of products is something no one can foresee. We cannot base sales forecasting for remanufactured products on current sales. Remanufacturing is something which will pay off in the long-term and this is how it should be perceived – as a long-term strategy. In the short-term, remanufacturing is not profitable. Moreover, we never know how markets respond. In some markets, remanufactured products represent 70% of all aftermarket sales; in other markets remanufactured products are not demanded at all.*[40]

The author asked if data of the current car park could be used to forecast demand for remanufactured engines. The manager for commercial vehicles engines (at the Global Warehouse) explained that forecasting, which is based on the amount and age of cars in the market, is not reasonable. According to the respondent, such data would not provide any information on how the car engines had been used. The data would also not indicate the time or quantity of (future) core returns. In the interviewee's eyes, the only reliable data could be obtained from the retail level, since retailers possess data on vehicle use and the replacement of wear and tear parts, for example.

[40] Quoted from the interview with the Product Manager Remanufactured Parts at Case Company A's Headquarters, February 2003. Translated from German; partially cited in Seitz and Peattie (2004).

Figures 18 to 21 show engine manufacturing and remanufacturing figures for selected engines between 1980 and 1998. These graphs give an indication of how the two product life cycles, new and remanufactured, relate. This information may assist in forecasting future demand, however, Figures 18 to 21 also show that life cycles differ very much between engine models. Two of the criteria for the graphical display of a specific engine model were the length of the life cycle an individual engine model could provide, but also data availability. A particular problem of picturing the engine life cycles was the fact that remanufacturing volumes in the timeframe (1986 – 2001) only represented a very small percentage of the overall engine manufacturing volume. Hence integrating both life cycles into one diagram was challenging. The full list of figures (database) for all engine models can be found in Appendix .J

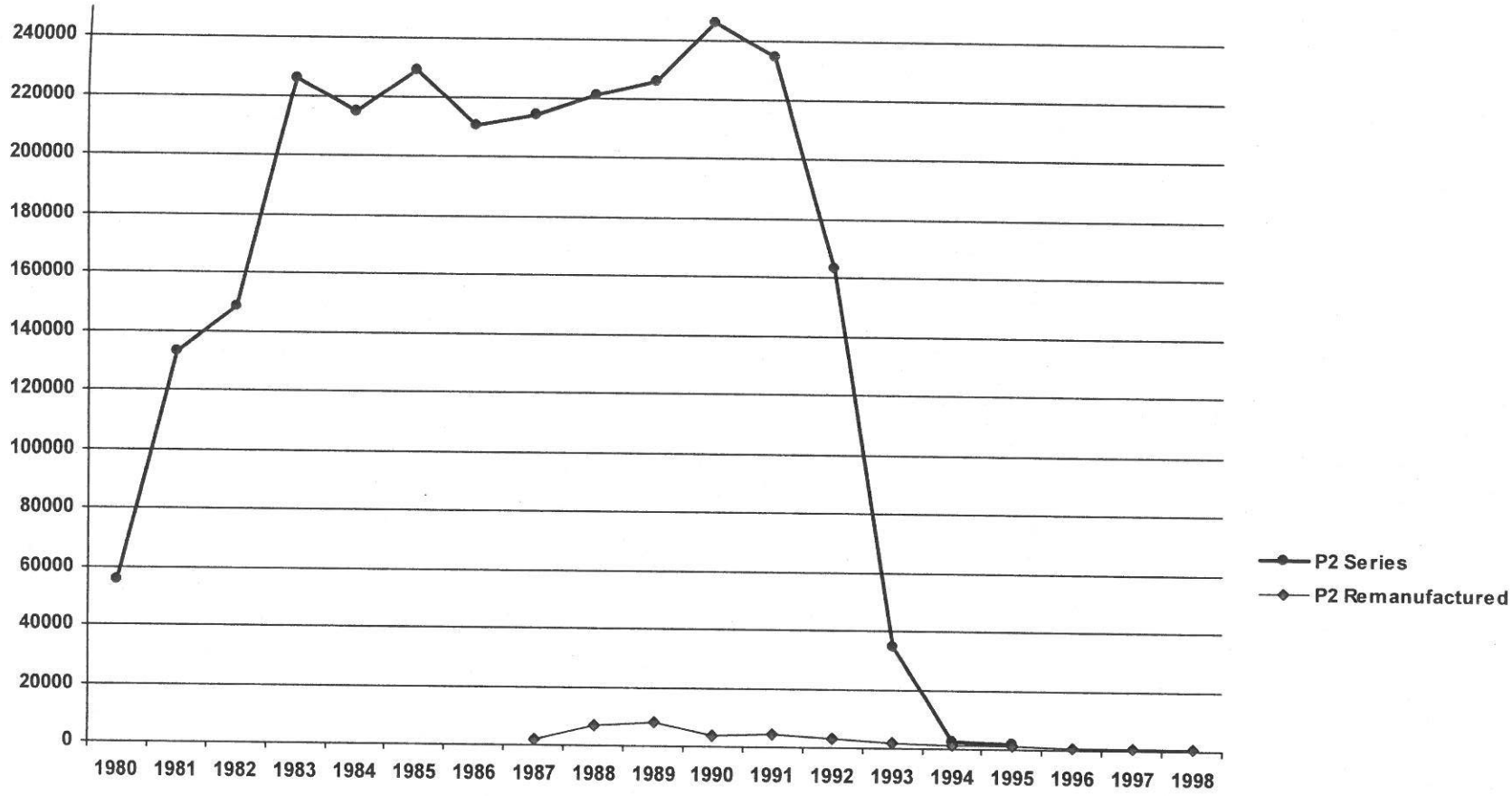


Figure 18: Product Life Cycles Petrol Engine Model P2

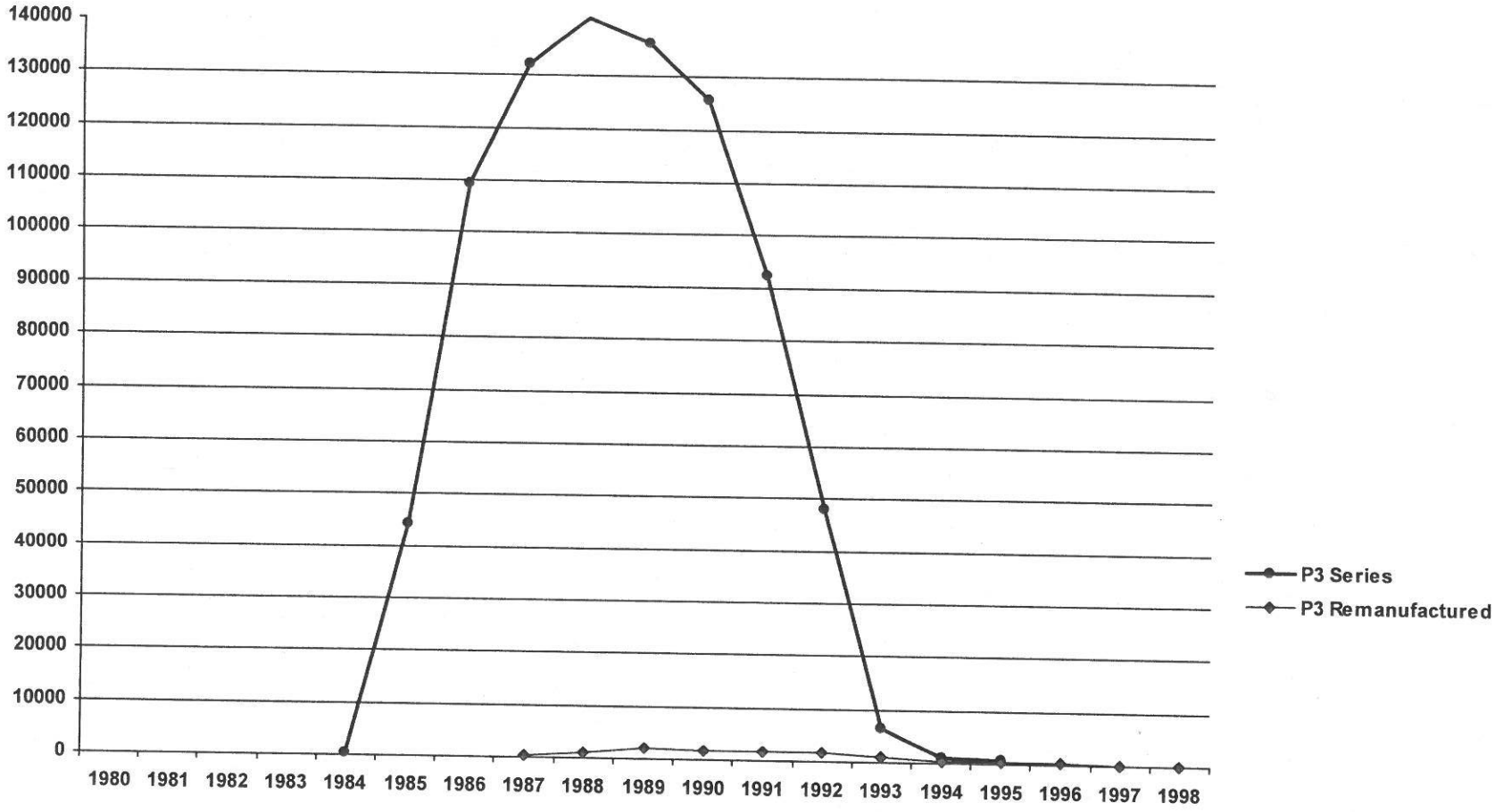


Figure 19: Product Life Cycles Petrol Engine Model P3

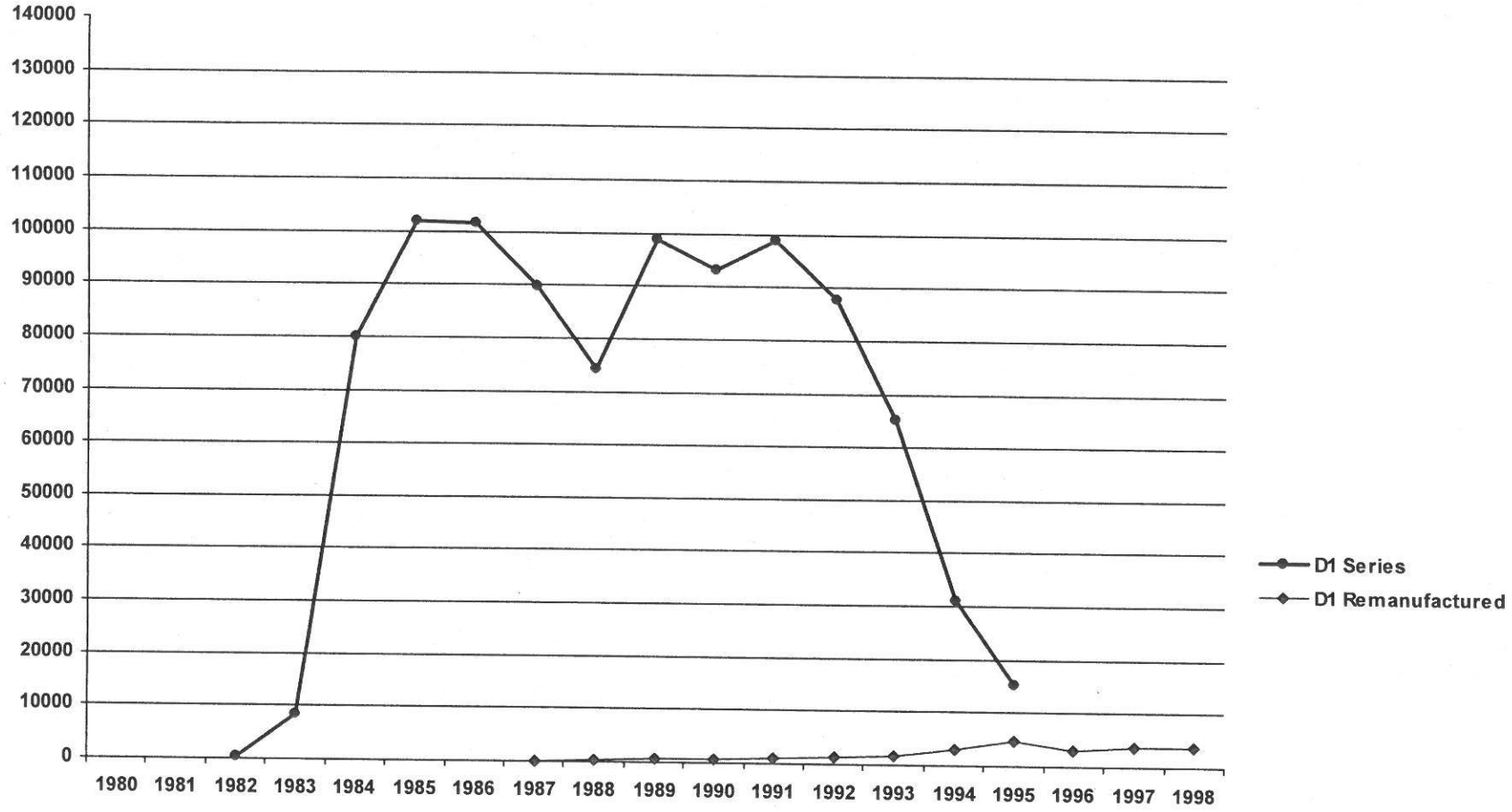


Figure 20: Product Life Cycles Diesel Engine Model D1

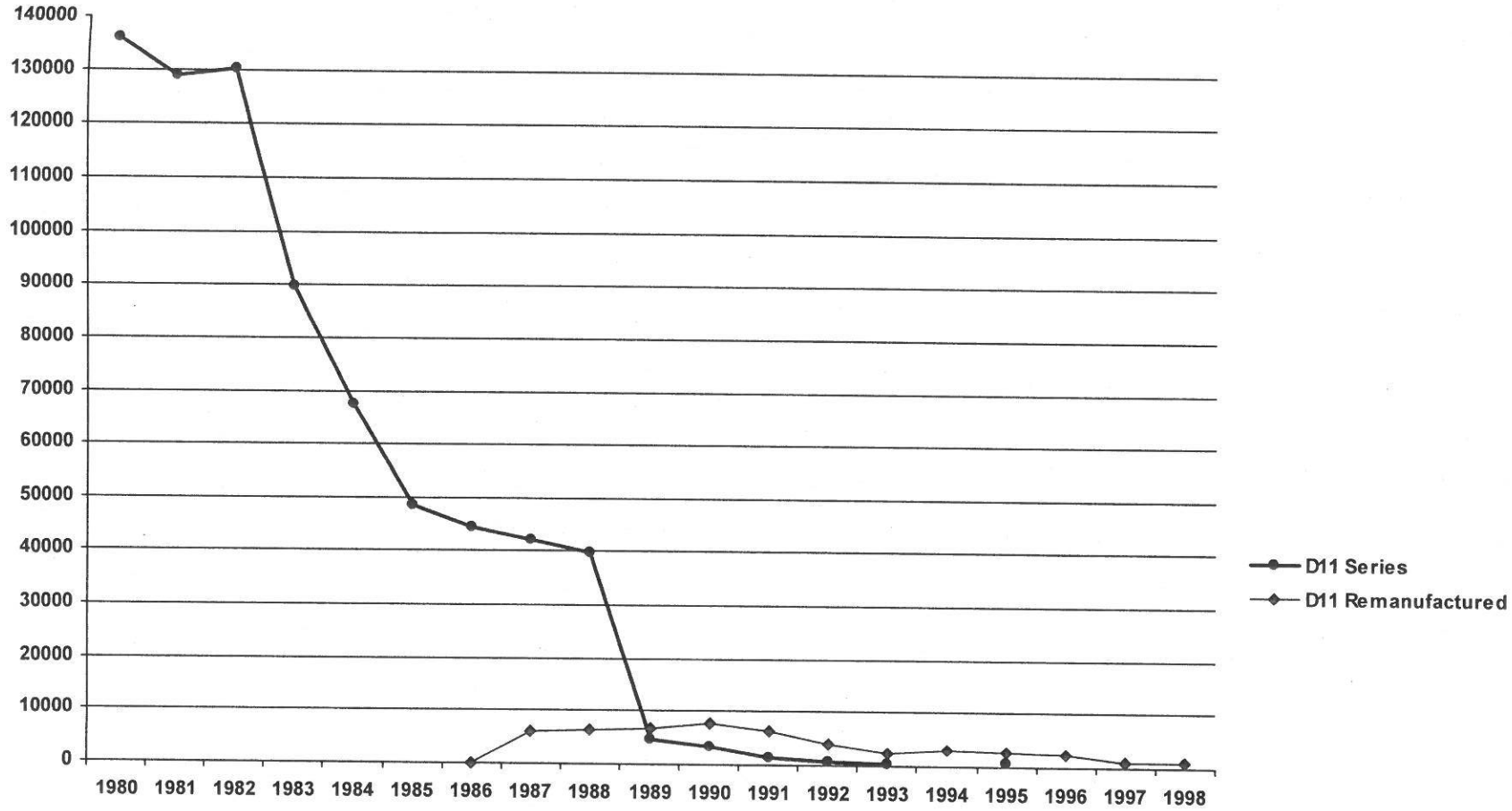


Figure 21: Product Life Cycles Diesel Engine Model D11

A comparison between all figures in the database (Appendix J) shows that on average, remanufacturing of an engine model has begun five years after the outset of the same engine model's manufacturing process. However, it was discovered that over the years, the time span between serial production and remanufacturing was reduced. As an example, the diesel engine model D1 was firstly remanufactured six years after the introduction of the new engine in 1982/83. The remanufacturing life cycle of the petrol engine model P7, on the other hand, began three years after the start of production in 1996/97.

Moreover, assumptions could be made with regard to the expected return volumes for engine models. Although for some engine models, data was available for the years before 1980 and after 1998, the database indicated that the overall remanufacturing volume of engines varied strongly, depending on the engine model, but never exceeded 5% of the original production. For example, the manufacturing volume of engine model P3 amounted to 838,055 engines (years 1984 to 1995). Remanufacturing of this engine began in 1987, with an overall volume of 10,958 (10,853 engines from 1987 to 1989 and 105 engines between 1999 and 2001, see Appendix J and Table 38). This results in a remanufacturing volume of 1.31% of the original production. Further figures could be calculated for the following engine models:

- Petrol engine P5: engine return volume of 0.54% of original production (908,505 manufactured and 4,889 remanufactured engines)
- Petrol engine P9: engine return volume of 0.15% of original production (946,255 manufactured and 1,457 remanufactured engines)
- Petrol engine P10: engine return volume of 0.22% of original production (359,525 manufactured and 807 remanufactured engines)
- Petrol engine P11: engine return volume of 0.15% of original production (531,398 manufactured and 787 remanufactured engines)
- Diesel engine D3: engine return volume of 4.5% of original production (269,274 manufactured and 12,156 remanufactured engines)

- Diesel engine D10: engine return volume of 0.5% of original production (1,518,961 manufactured and 7,342 remanufactured engines)
- Diesel engine D11: engine return volume of 4.22% of original production (1,219,759 manufactured and 51,569 remanufactured engines)

6.5 Pricing of Remanufactured Engines

Although access to financial data was limited, certain data could be obtained. This section discusses how the sales price for remanufactured engines was calculated. It also defines the 'exchange price' and explains which aspects may have had an impact on the profitability of remanufactured engines.

One of the major issues within the calculation of prices for remanufactured engines was the fact that limited cost data for remanufactured engines seemed to be available within the remanufacturing plant. The remanufacturing plant used to be organised as a profit centre. Interviewees explained that this had an effect on the overall pricing structure of the plant. Since profit centres were evaluated by their annual profit, the OEM remanufacturer negotiated prices with suppliers, which were taken on as 'costs' within the accounting system. Cost analyses were therefore based on prices that had been negotiated and real costs remained unknown. At the time of the research, the remanufacturing plant was still in transition from a profit centre to an independent centre of the group. At the same time, the controlling department sought to calculate new prices for remanufactured engines. However, the controllers did not necessarily understand or recapitulate the inputs (e.g. parts, labour, energy) into individual engine variants. Most calculations were based on historical data. The author therefore assumed that pricing at the remanufacturing plant, which referred to the prices the Global Warehouse had to remunerate for the engines, were calculated rather arbitrarily.

The prices for retailers were calculated by controllers in the company's Headquarters. While it is unclear to what extent these considered the 'purchase price' from the remanufacturing plant, according to the interviewees, three factors played a role within the price-building process for the retail level. Firstly, the basis for the calculation was the price of a new engine (same engine variant). Secondly, since customers would not

have purchased a remanufactured engine that is more expensive than a new aggregate, approximately 10% of a new engine's price was deducted. Thirdly, 'market adjustments' were considered. Such market adjustment may have referred to the demand in the market, the prices of competitors or the life cycle of the engine, for example[41]. This price was generally known as the list price of remanufactured engines. The so-called 'exchange price', the actual price which had to be paid by the customer, was expressed through the deduction of the rebate from the list price.

Exchange Price:

- Price of a new engine
- Approximately 10% deduction
- Market adjustments
- Deduction of the rebate

According to one interviewee, prices which would be purely based on the actual costs that had occurred from the acquisition of a core to the distribution of the remanufactured engine would have been unrealistic and not competitive in the market.

The following figures in Tables 45 and 46 give an example for a four-cylinder petrol and diesel engine. The manufacturing of the petrol engine began in 1997 and in 1998 the company began to produce diesel engines (see also engine models D14 and D16 in Appendix J). The first engines were remanufactured in 1999 (see Table 38).

[41] As it will be outlined in Chapter Seven, it is questionable whether the VM really knew the market for remanufactured products (see quote in Section 7.6.3). For the author, pricing seemed to be based very much on historical data rather than a sound calculation. The author had the impression that prices were calculated arbitrarily, since the controllers were neither aware of market conditions nor engine technology.

Engine	New Engine		Remanufactured Engine			
	Prime Cost Global Warehouse	Price for Retailers	Production Cost Remanufacturing Plant	Prime Cost Global Warehouse	Rebate	Price for Retailers
P16 Variant 1	1,549	3,242	1,968	1,916	963	3,048
P16 Variant 2	1,456	3,472	1,949	1,518	963	3,048
P16 Variant 3	1,382	2,413	1,799	1,959	511	1,961
P16 Variant 4	1,383	2,413	1,798	1,897	511	1,961
P16 Variant 5	1,301	2,806	1,795	1,979	741	2,426
P16 Variant 6	1,386	2,806	1,793	1,976	741	2,426

Table 45: Petrol Engine Cost Comparison in 2002 (in Euros)
(Source: documentation and interviews – Case Company A)

Engine	New Engine		Remanufactured Engine			
	Prime Cost Global Warehouse	Price for Retailers	Production Cost Remanufacturing Plant	Prime Cost Global Warehouse	Rebate	Price for Retailers
D14 Variant 1	2,510	4,377	3,011	3,104	1,214	3,741
D14 Variant 2	2,426	4,377	3,013	3,234	1,214	3,741
D14 Variant 3	2,503	4,377	3,021	3,292	1,214	3,741
D14 Variant 4	2,416	4,377	3,068	3,364	1,214	3,741
D14 Variant 5	2,486	4,377	2,980	3,195	1,214	3,741
D14 Variant 6	2,402	4,377	2,985	3,228	1,214	3,741
D14 Variant 7	2,616	4,377	2,913	3,087	950	2,925
D14 Variant 8	2,496	4,377	3,018	2,747	1,214	3,741
D14 Variant 9	2,588	4,377	3,003	3,274	1,214	3,741
D14 Variant 10	2,497	4,377	3,003	3,249	1,214	3,741
D14 Variant 11	2,581	4,377	3,003	3,274	1,214	3,741
D14 Variant 12	2,491	3,934	3,003	3,232	1,155	3,517

Table 46: Diesel Engine Cost Comparison in 2002 (in Euros)
(Source: documentation and interviews – Case Company A)

Although these figures only provide a very narrow impression of the overall picture, they demonstrate that pricing seemed to be oriented at flat rate prices for engines from the same model. Hence, retailers could have purchased different engine variants for the same prices, although accounting costs for remanufacturing differed. It may be assumed that this was based on the fact that the vehicle manufacturer has been remanufacturing a vast amount of engines, so that more accurate pricing was not justified. Also, one interviewee stated that retailers had not understood why there were different prices for different engine variants (of the same model) and therefore, retail prices had to be adjusted to the same level.

Moreover, since, at the time of the research, this was a relatively recent engine model, the prime costs for a new engine were lower than the costs for remanufacturing. It may be assumed that for older engine models, remanufacturing will evidently become the cheaper option, for example when the original manufacturing plant reduces the production volumes or ends production. However, for retailers, a remanufactured engine has to be the cheaper option from the beginning of the engine life cycle. Otherwise, new and remanufactured engines would compete in the same price category. Appendix K provides a price comparison between new and remanufactured engines.

However, further considerations have to be made with regard to OEM remanufacturing. Firstly, Vehicle Manufacturer A used the extensive network of subsidiaries and franchised dealers for core collection and the distribution of remanufactured goods. At the time of the research, subsidiaries did not receive a discount for the goods they purchased from the Global Warehouse. However, franchised dealers based in Germany received an average discount of 17%. This had the following implications on the profitability of remanufactured engines. Franchised dealers could purchase remanufactured engines for 83% of the retailer list price (see Tables 45 and 46), but would have received only 83% of the rebate. As a result, in the case of some engine variants, the vehicle manufacturer made a loss. This statement can be confirmed with the calculations for one P2 engine variant.

> *In Germany, the franchised dealer receives a discount of 17%. He buys from us for 100% minus 17% = 83%. For the return of this particular core, the franchised dealer receives 83% of the rebate (20.19% in our example) = 16.76% of the list price. The exchange price is therefore equals 83% minus 16.76% = 66.24%. Our profit/loss is therefore 66.24% minus 76.65% = - 10.41% the gross list price. Funny, isn't it?* [...] *Back to our example. We have sold just one engine of this variant in the last couple of years. Since the so-called 'old model' would be lying in stock 'as heavy as lead', this low price was the cheapest opportunity to avoid an inescapable scrapping.* [...]. *Important is the overall view and the consideration of all engines, as discussed in the interview: warranty – which we pay anyway - and the ability to supply across the whole car life cycle.*[42]

[42] Quoted from personal communication (E-Mail) with the Product Manager Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, October 2004, translated from German.

Moreover, the profitability of the remanufacturing operation was even more endangered considering the fact that at the time of the research, franchised dealers outside Germany received discounts between 15% and 25%. However, interviewees claimed that around 60% of all remanufactured engines were distributed within Germany and that franchised dealers accounted for two-thirds of the overall market.

6.6 Generic Issues and Observations - Engines

This section aims to summarise and compare the generic issues in product recovery management and remanufacturing that were discovered in the literature in Chapter Two with the empirical observations made within the case study research. Firstly, the generic issues outlined in Sections 2.4 and 2.5 are matched against the observations within Case Company A. Thereafter, further observations made in the research are listed.

	Generic Issue/Problem Area	Observation/Current OEM Practice
Issues Identified in the Literature	Collection structure complexity	▪ No issue within Case Company A ▪ Forward distribution network is used for product take-back (reverse logistics)
	Integration of forward and reverse flows	▪ Consolidation of forward and reverse flows ▪ Existing forward distribution network takes on product collection and distribution
	Complex inventory management	▪ High engine core levels to eliminate return uncertainty ▪ High stock levels for parts
	Production planning and control	▪ Manual production planning ▪ Lack of manpower; one production scheduler only ▪ Lack of computer system support
	Finding markets for remanufactured products	▪ Remanufactured products compete with new products of different qualities and prices ▪ Remanufactured products also compete with used or repaired parts in the aftermarket
	Uncertainty in timing and quantity of returns	▪ High inventories to buffer return uncertainty ▪ Financial incentives (rebate) to ensure return to the OEM
	Uncertainty in quality of returns	▪ High scrap rates for various parts ▪ Reduction of rebate for damaged cores
	Product disassembly	▪ Large amount of manual labour required ▪ High lead times due to dirt, rust, oil
	Design for remanufacturing	▪ Currently not applied in the engine sector ▪ Timeframe between engine design/manufacturing and return is vast: design for remanufacturing only comes into effect after decades

Table 47: Matching Generic Issues in the Literature with Case Study Observations – Part 1

	Generic Issue/Problem Area	Observation/Current OEM Practice
New Observations	Order fulfilment and delivery	▪ 20 days for average regular runner engine ▪ 40 days for an irregular runner ▪ 50 days for a stranger
	Delivery times for parts	▪ Long delivery times for parts remanufactured externally ▪ Long delivery times for new parts; 'the line comes first'
	Product variation	Different types of product variation provide obstacles in the remanufacturing environment: ▪ Different engine generations ▪ Different engine variants (personal customisation, horsepower, fuel type, technological upgrades) ▪ Different engine qualities at the time of return
	Recovery/ Re-assembly process	▪ The Case Company sought to replicate mainstream engine production due to high product variation ▪ Skilled labour required
	Demand forecasting	Currently not practiced, due to: ▪ Unsuccessful previous attempts to forecast demand (by Global Warehouse) ▪ Lack of manpower to develop sophisticated forecasting model ▪ High demand variation between engine models (see Tables 31 to 34) ▪ Remanufacturing is a non-core business

Table 48: Matching Generic Issues in the Literature with Case Study Observations – Part 2

6.7 Conclusion

This chapter has presented the results of the first in-depth case study. The chapter has firstly outlined the major characteristics of an OEM exchange process. Thereafter, the closed-loop supply chain including the core, product and order flows was presented and discussed.

The second part of the chapter has described the main steps of an engine remanufacturing process, which also comprised the presentation of detailed process data. The in-depth analysis of the remanufacturing process has revealed complicating factors, uncertainties and inefficiencies within OEM engine remanufacturing, such as the dependency on internal and external parts producers, product variation and demand forecasting. Compared to (smaller) independent remanufacturers, the OEM engine remanufacturing process seemed to be rather inflexible. There is a significant buffer stock of 8,000 remanufactured engines at the Global Warehouse. Parts were recovered according to the orders placed by the customer (Global Warehouse). However, the order was not related to market demand.

The chapter has concluded with the explanation of the pricing structure for remanufactured engines. The subsequent chapter will continue the in-depth description of the case study research with a detailed presentation of the results from the second main case study on electronic device remanufacturing.

Chapter Seven
Electronic Device Remanufacturing

7.1 Introduction

This chapter aims to present the case of electronic component remanufacturing. It seeks to demonstrate the differences between mechanical remanufacturing and electronic remanufacturing from an empirical point of view. The main case study in this chapter outlines the issues incorporated in the product recovery of the electronic car components, as well as the motives behind the increasing interest in recovering electronic components, such as head units.[43] This chapter hereby aims to provide the basis for answering Research Questions 1 and 2 for electronic component remanufacturing. Moreover, the results of this chapter will contribute to the discussion and analysis in Chapters Ten and Eleven.

First of all, the chapter gives an overview of typical factors, which have to be considered within electronic component remanufacturing. These are significantly

[43] 'Head unit' is a general term for an electronic car device, which is found in the car dashboard and may be a radio, tape-deck or CD-player. However, particularly in luxury cars, these head units have developed into multi-functional and complex board management systems. The devices are not just entertainment units, but manage other functions in the car, such as air-conditioning, navigation display and communication (telephone). In this chapter, the term head unit will therefore always refer to a cockpit management system which includes these additional functions.

different from what has been observed in the mechanical remanufacturing of automotive engines. This chapter therefore clearly demonstrates that remanufacturing processes, issues and obstacles have to be investigated separately and per product group, even for products that find application within the same industry.

This chapter also presents an overview of the issue of post-serial supply, a topic which has already been briefly discussed in Chapter Five. The different product recovery options are discussed for electronic devices, followed by a classification of product return types which have occurred in the Case Company in 2003. The chapter hereby differentiates between the suppliers' and the vehicle manufacturer's perspectives with regard to electronic device remanufacturing.

7.2 General Case Description

Chapter Two has outlined that European automotive remanufacturing has begun with mechanical components, such as engines, clutches or gearboxes. Electrical components, such as alternators, starter motors and other small motors followed. However, this research has discovered that first efforts of remanufacturing electronic devices were undertaken by original equipment suppliers in the German head unit market in 1998/1999. The chapter will illustrate how these operations and processes were undertaken in the year 2003. Since the remanufacturing of electronic components has only begun in the late 1990s, businesses show less experience with the remanufacturing of these components, compared to the remanufacturing of mechanical components. This also had an impact on this research. While historical data was available for engine remanufacturing, less data could be found for electronic device remanufacturing. Moreover, data was dispersed even more along the closed-loop supply chain, since most electronic components are supplied to the vehicle manufacturer. Hence, original remanufacturing is also undertaken by first-tier suppliers. In addition, the product characteristics of electronic devices make the remanufacturing process less visible and therefore less traceable. It also means that detailed data on the individual remanufacturing process steps was not available.

The electronics case study material was collected during a four-week work placement in Germany in 2003, which the author spent working on a project at the vehicle manufacturer's Global Warehouse. The author's stay included a visit to one of the company's German electronics suppliers. In addition, further fieldwork was conducted on the premises of a second, German supplier in July 2003. The second fieldtrip was more comprehensive from an operational perspective, since it involved process observations in the remanufacturing plants. Case Seven (see Figure 10 in Section 4.3.2) provided most of the data discussed in this chapter. In total, more than forty interviews were conducted with employees from all functional levels. To avoid confusion with the first case study, which was conducted in the facilities of the same vehicle manufacturer, the Case Company will be named 'Company B' for any matters concerning the remanufacturing of electronic components. The suppliers are identified as 'Company C' and 'Company D', respectively.

This chapter presents electronic component remanufacturing from two different angles: the vehicle manufacturer's position and motives, as well as the supplier's standpoint. The vehicle manufacturer's view has been comprehended during the work placement in the project team for electronics remanufacturing at the Global Warehouse. The idea of working directly with the project team members provided an opportunity to obtain first-hand insights into the remanufacturing of electronic devices.

7.3 The Specific Characteristics of Electronic Devices

This section seeks to discuss the differences between electronic and mechanical components in cars. Some characteristics, such as the short life cycle of semiconductors and chips, have an impact on long-term supply and remanufacturing. One of these issues is the problem of providing replacement parts after product phase-out. In the following, an electronic car part, such as a radio or navigation system, or a head unit, will be referred to as an 'electronic device', rather than electronic components. This distinction is required, since electronic device producers often refer to components as the specific semiconductors and chips on the integrated circuit board.

However, electronic devices often consist of several parts, the so-called modules. For their original car parts, vehicle manufacturers may demand modules from different

manufacturers, which are then assembled into the complete device by one of the suppliers (in most cases one of the manufacturers), the company with the 'system responsibility'. The system supplier is also responsible for the coordination of the other electronic manufacturers which supply the remaining modules. As a result, electronic (module) manufacturers have to co-operate with competitors if the vehicle manufacturer decides to procure parts from more than one source. Siemens Automotive VDO, Harman/Becker Automotive Systems and Nokia, for example, may therefore need to co-operate in the production of an electronic device. In the case of complex cockpit management systems or head units, this is the norm. However, difficulties occur in the event of product failure, since the faulty module (i.e. the liable module manufacturer) has to be identified.

The Share of Electronics in Cars

The share of electronic components in automotive vehicles increases steadily. Cars might nowadays contain up to 50 microprocessors. Some of the reasons for the increase in the share of electronic components refer to the need for a powerful and sophisticated engine control system, in order to meet emission and fuel-economy standards. Moreover, the incorporation of new safety, comfort and convenient features, as well as the reduction of the amount of wiring in the cars has increased the amount of electronics in cars. The engine's control unit is usually the most powerful computer in a car. It controls the engine functions such as spark timing, fuel-air ratio, emissions and fuel economy of the engine. The ECU gathers data from a variety of different sensors and hence registers, for example, the coolant temperature, the engine speed and the amount of oxygen in the exhaust (Howstuffworks, 2002).

In the year 2002, it was estimated that electronic parts have reached a share of 25 percent of the production cost in a vehicle from the high-end of the market. This share is expected to increase to 30 percent in the near future (Filser, 2002). This was confirmed by the team leader for electronic parts and components at Company B's Global Warehouse, who explained that the amount of electronic components in cars has not reached its peak, yet. At Company D, the manager for IT integration noted that each car

contains around 30 to 40 small electric motors (e.g. motor for windshield wipers, electric window, sunroof or seat adjustment). According to the interviewee, technological changes and improvements have reached their peak in this respect. With regard to head units, the interviewee expected further innovations, since these contain prospects on profits. However, there is a distinction between Europe and the United States. At the time of the research, the main share of the European market for navigation systems, for example, was split between the Siemens VDO Automotive AG (29%), the Blaupunkt GmbH (29%) and Harman/Becker Automotive Systems (16%). In the United States, on the other hand, the demand for navigation systems was far below the European demand. According to the interviewee, this is due to the square arrangement of streets, in which drivers may find it easier to find their destination.

Electronic Supply Chain Structure

As outlined in Chapter Five, the engine supply chain is far more transparent than the supply chain for electronic components. In the engine supply chain, the vehicle manufacturer is mostly in control of the process, the product design and possesses product design information. However, this is different to the electronic device supply chain, since electronic component suppliers deliver the complete product. As previously discussed, the electronic component suppliers (i.e. the semiconductor manufacturers) mainly supply to other, more lucrative industries, such as the computer, communication, and consumption industries. The automotive industry therefore plays an inferior role from the semiconductor producer's perspective.

The chip manufacturing sector is characterised by very high production volumes.[44] The industry contains a limited number of global players, and signalises over-capacity and low profit margins. It is therefore difficult for vehicle manufacturers to control this industry sector, since only five percent of the worldwide semiconductor market provides

[44] Within the production of a chip, sand is firstly converted into ingots, thereafter cut into thin slices to form silicon wafers which are planarised, then mechanically and chemically polished. Wafers are processed and transformed into chips. One chip can carry thousands of transistors ('bits' of storage). Chips, LEDs (Light Emitting Diodes) and transistors are all made from semiconductor material. For more information, see Gortol *et al.* (2003) and Howstuffworks (2001).

products for automotive supply (Schumacher, 2002). These figures are different for semiconductor consumption in Europe, in which the automotive sector accounts for nearly seventeen percent (Hofmann, 2003). However, the computer and communication sectors dominate two-thirds of the market, also in Europe (Hofmann, 2003). As will be shown later in this chapter, this has a strong impact on power-related issues in the electronic component supply chain. Figure 22 shows a typical electronic device supply chain.

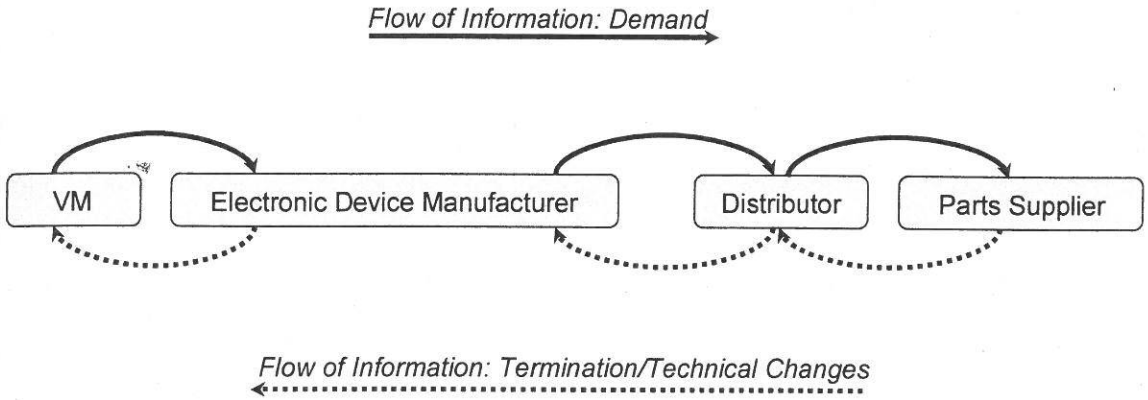


Figure 22: Typical Supply Chain for Automotive Electronics
(Source: reproduced from ZVEI, 2002, p.10)

Conflicting Product Life Cycles and the Impact on the Replacement Market

The automotive industry benefits from the short innovation cycles and therefore the short product life cycles of the semiconductor industry (ZVEI, 2002). In this way, vehicle manufacturers have been able to offer the car buyer the most recent technology. However, a reduced time-to-market in so-called 'fast cycle' industries with product life cycles of approximately two years has impacts on the automotive industry. Geismann (2003) notes a development phase of three to five years and a use of up to twenty years for cars, compared to three quarters of a year of development and three to five years of use for electronic components. As a result, at the beginning of this century, it was increasingly difficult to provide spare parts from the 1980s and 1990s (Geismann, 2003). The aim of providing spare parts for ten years or more does not harmonise with the production philosophies of the semiconductor industry, where components are being

produced for a short time, thereafter being replaced by an improved version (ZVEI, 2002). Filser (2002) states that the differing product development cycles are the main cause of the vehicle manufacturer's dilemma with regard to spare parts supply.

> *The semiconductor industry is under a lot of pressure for innovation, particularly in the area of information technology. Products in the computer and telecommunication industry just disappear after a couple of years and can easily be replaced in the event of damage, rather than being repaired. However, vehicle manufacturers face another problem: they are obliged to provide spare parts for 25 years.*
>
> (Filser, 2002, p.7, translated from German)

The conflicting product life cycles have impacts on the automotive sector. In some cases, semiconductor suppliers stop production even before the first vehicle, containing a particular device, has been assembled (Schumacher, 2002). The device manufacturer, in this case the electronics (first tier) supplier, is allowed a further 18 months to procure these parts for the last time.[45] Therefore, many electronic device manufacturers have departments, which focus solely on the management of those so-called 'discontinuation of deliveries'. In Case Company D, there are around 50 discontinuations every month.

> *Semiconductor suppliers don't like the first tier electronic suppliers, since the semiconductor suppliers are not able to deal with durable products. In our company, there are around 50 PTNs* [Product Termination Notification] *every month. Within first tier electronics suppliers like us, there are departments, dealing with nothing but PTN management.*[46]

Similar statements were made by Supplier C, who also seemed to manage discontinuations without the help of the VMs. According to one interviewee, semiconductor manufacturers usually provide a replacement for a discontinued chip, often produced by another company. If that is not the case, this specific supplier applies specific warehousing techniques, in which the modules can be stored for up to 16 years.

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[45] The strategy of purchasing certain spare parts for the last time before production lines are closed down is often referred to as 'all-time-buy'. Thereafter, the product can not be procured any longer.

[46] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at case Company D, July 2003, translated from German.

However, Company C also believed that the issue of post-series supply has been less severe than it was promoted by the VMs and the industry organisations, such as the *Zentralverband der Elektrotechnik- und Elektronikindustrie* ('German Association of Electrical and Electronic Manufacturers', ZVEI, 2002).

"After ten years, no car owner is interested in an out-dated radio or a CD player any more. Therefore, a discontinuation of delivery by semiconductor suppliers is not as serious as vehicle manufacturers picture the problem" stated the key account manager of Company C. This statement implies that post-serial supply of entertainment units is less critical than the post-serial supply of components that are critical to the operation of a car. However, the issue of post-serial supply for components that are critical to the operation of a car, such as an engine control unit, for example, still seems to remain.

The Vice President of the OES market segment at Company D was further asked why vehicle manufacturers, such as Company B, have become so interested in managing PTNs, an issue which would be seen as the supplier's problem since it does not directly affect the vehicle manufacturer. He responded that there are two main reasons.

First of all, vehicle manufacturers are concerned about their supply of replacement parts, which suffers in the case of the unavailability of semiconductors.

The second main reason for vehicle manufacturers to be interested in PTNs is the wish to keep prices for replacements parts low, since these usually increase after the phase-out of a product series. By trying to manage the semiconductor supply, some vehicle manufacturers aim to control price increases of post-serial parts procurement. Consequently, this results in more control over parts and price management.

There are further issues. Semiconductor suppliers, for example, are often unaware of the end-customer, in this case, the vehicle manufacturer. As a result, vehicle manufacturers do generally not receive the information about a discontinuation of delivery. Moreover, vehicle manufacturers are unaware of any contractual obligations between supplying parties (electronic supplier – semiconductor relationships). In addition, the vehicle manufacturer has no influence on the semiconductor manufacturer's decision (ZVEI, 2002). However, it is the vehicle manufacturer, who will be made responsible for not being able to deliver a certain spare part.

7.4 Post-Serial Supply

In order to secure the supply of replacement parts after a car model phase-out, there are a variety of strategies for electronic devices to serve the so-called post-serial or non-serial supply. Generally, the management of replacement parts is difficult for any automotive part, since product outflows vary; aftermarket discounts as well as the use of similar parts for the same application distort aftermarket demand (Kühlwein *et al.*, 1999). The complicating factors of post-serial supply of replacement parts will be discussed in the following.

Burghoff (1999) argues that the management of spare parts after the car model phase-out differs to a large extent from the supply of a current assembly line. The problem of the so-called 'non-series supply' (Burghoff, 1999) seems to be not just an issue with regard to electronic parts and components in particular, yet the countermeasures have to be investigated separately and per product.

In Burghoff's eyes (Burghoff, 1999), non-series supply is crucial for the availability of replacement parts to the right quantity and at the right point of time. In the case of mechanical components (e.g. clutches, engines, water pumps), there is only the question with regard to how many products should be taken on stock and which financial impact this measure has in terms of bound capital and warehouse costs. As will be shown later in this section, the storage of electronic components is far more difficult than storing mechanical components. Burghoff (1999) concludes that there are further issues, which have to be considered:

> *To sum it up, the overall picture doesn't look very good. We don't know the future demand of individual control units, modules or components. We don't know how much it costs to secure post-serial supply. We are therefore facing a supply gamble, which cannot be determined, neither in quantitative, nor in qualitative terms.*
>
> (Burghoff, 1999, p.7, translated from German)

The different strategies of how vehicle manufacturers may approach the issue of securing electronic replacement parts include 'all-time-buy', the redesign of a device or one of its components as well as the repair, re-use and remanufacturing of devices.

Final Stocking – 'All-Time-Buy'

One of the strategies applied by Vehicle Manufacturer B was the request for a one-time and final manufacturing of a particular number of products. These were put on stock and distributed according to demand. However, the drawbacks of this strategy were the storage costs and the limited shelf life of electronics. Company B stored partly manufactured products, components as well as semiconductors.

Semiconductor storage has always been problematic. Corrosion or technical problems may occur during and after long-term storage. The probability of installing a semiconductor without problems decreases by the increase of years of storage. However, in the case of a discontinuation of delivery, the storage of semiconductors or other components (e.g. wafers, chips or integrated circuits) is the only option. These items might be low in price when procured in high quantities, but storage can be very costly. According to Schumacher (2002), the storage in special dry-packs may ensure a supply for 16 years, compared to the usability of one to four years with conventional measures, as assumed by ZVEI (2002). Dry-packs are special bags made from a foil-coated metal. The dry-packs are air-sealed and contain a desiccant. Components can be stored in a dry-pack for four years, but the bag can be 'refreshed' several times. According to a study within Company B, not the company itself, its electronic component suppliers or the semiconductor distributors had expertise of semiconductor long-term storage. Other options, mainly used in the military sector, are air-sealed tins or nitrogen cupboards. However, these measures have been identified as too expensive for the automotive sector (see also ZVEI, 2002).

Repair of Electronic Devices

A clear distinction between the different product recovery options has been drawn in Chapter Two. However, the difference between repair and remanufacturing of electronic components is less apparent than it is with regard to mechanical components. Mechanical car components can be repaired to 'working order', whereas remanufacturing involves the reconstruction to an 'as good as new' standard. In the case of electronic devices, repair only involves the elimination of the fault, which caused the product failure. The identical part is returned to the car user. Hence, no 'exchange' for a

completely different product takes place. The car user may therefore find the same traces of use on a repaired device (e.g. scratch on the front cover). Remanufacturing includes further steps, such as the application of the most recent software and the exchange of the device's front covers in order to give the product 'an as good as new' appearance. For a layman, the difference between remanufacturing and repair of an electronic device may be less apparent, since remanufacturing incorporates 'invisible' processes, such as software amendments. However, as a later section on the electronics remanufacturing process will demonstrate that also the individual remanufacturing process steps are less traceable.

Re-Use and Remanufacturing

Re-use of electronic devices from ELVs or cars that were involved in accidents may provide some spare parts for the aftermarket (Geismann, 2003). On the other hand, used devices can be remanufactured. In both cases, repair and remanufacturing, a reverse logistics network is required. In addition, there is the necessity for elaborated quality inspection, remanufacturing and storage facilities, as well as skilled labour. The electronics remanufacturing process will be discussed in detail later in this chapter.

Redesign of an Electronic Device

Geismann (2003) claims that the completely new construction of an electronic device (redesign) is expensive and undesirable, since costs have to be allocated to a small number of devices. Company B has defined 'redesign' as the complete reconstruction of the hardware of a new product, which may also replace previous versions. The research and development department of Company B, which carried out redesigns charged a certain price for the first device (base variant), with a reduced cost for every additional product variant.

The strategy of a redesign has therefore been seen as the 'last resort' within Company B. According to Geismann (2003), a redesign is only reasonable if changes in the product layout are involved, in order to reduce variants. In addition, a complete reproduction of a discontinued chip or wafer, for example, is merely advisable if an appropriate

production volume is attained, so as to achieve economies of scale. This is less likely to be the case, regarding the overall volumes of chips and wafers needed in the automotive sector. According to Burghoff (1999), reproducing a product at a low volume is feasible regarding metal or plastic components – an activity which is still undertaken to provide replacement parts for classic cars. However, Burghoff (1999), who is a design and development specialist for battery technologies, does not provide solutions of how to reproduce control units after 15 years.

7.5 Current Remanufacturing Practice: The Supplier's Perspective

This section illustrates the supplier's perspective on electronic device remanufacturing. Particular emphasis is put on the reasons and procedures of take-back, the remanufacturing process, as well as the vehicle manufacturer's and the supplier's motivations to engage in remanufacturing. In the course of the research it was found that within electronic device remanufacturing there were a variety of product failure and return processes. These processes differed concerning logistics flows or financial implications. Therefore, this section defines the different product failure and return options among which Company D differentiated at the time of the research.

In-Plant Manufacturing Errors

From the supplier's perspective, product defects may have occurred before these were delivered to the customer. In most cases, these defects were discovered in the quality control process during manufacturing and the product may have been repaired. The location of product failure has therefore been the electronics manufacturing plant.

For Company D, this was the most inexpensive type of product failure and not a product return as such. Since the devices had not been delivered to the customer, no logistics costs emerged and no claims for compensation or replacement were made by the vehicle manufacturer.

Zero-Mile Returns

The second type of product defect was the so-called 'zero-mile-return' or 'assembly line failure', which occurred in the vehicle assembly plant. These returns included electronic devices, which had already been delivered to the vehicle manufacturer's plant, but the defect was observed before the cars have left the plant. Four different causes of product defects may have been identified. First of all, the customer, in this case the vehicle manufacturer, may have caused the defect through incorrect product storage at the assembly plant or faulty product handling during assembly. This source of defect is termed 'vehicle manufacturer fault', VMF, in the following. Secondly, the cause of fault may have originated from the electronics supplier's side and had not been detected in the quality control process, the so-called 'supplier fault', SF. Hence, the products were returned to the supplier, who was charged for transport and had to deliver a faultless product or compensates for the defects.

In addition, there may have been devices which appeared to be defective, but no fault was identified after a closer examination, the so-called 'no failure found' (NFF) devices. If the products were up to date with the current production, these may have been re-used directly in the vehicle assembly plant. The last category of product failure was the group of unknown defects, which were sent back to the supplier for closer examination. The difference between these defects and the NFF devices is the fact that NFF devices had appeared to be defective, but no fault could be found. Devices with unknown defects were truly defective, but the error could not be categorised as SF or VMF. In the automotive sector, 'no failure found' or 'no trouble found' products are very common, particularly in the electrical and electronics segment:

> *...why are returns, particularly the return of rotational electric components, so high? Especially when we are constantly being told that 40 percent or more of the units tested upon return to the manufacturer are found to be problem free? The most common answer is incorrect diagnosis. In other words, somewhere, some place, someone decided that an alternator or starter had failed when, in fact, the underlying problem was elsewhere to be found.*
>
> (Schneider, 2003, p.132)

All of these four categories are summarised as 'zero-mile-returns' in the following, since the defects are discovered within the vehicle assembly plant. Figure 23 demonstrates the logistics and financial flows occurring in conjunction with zero-mile-returns.

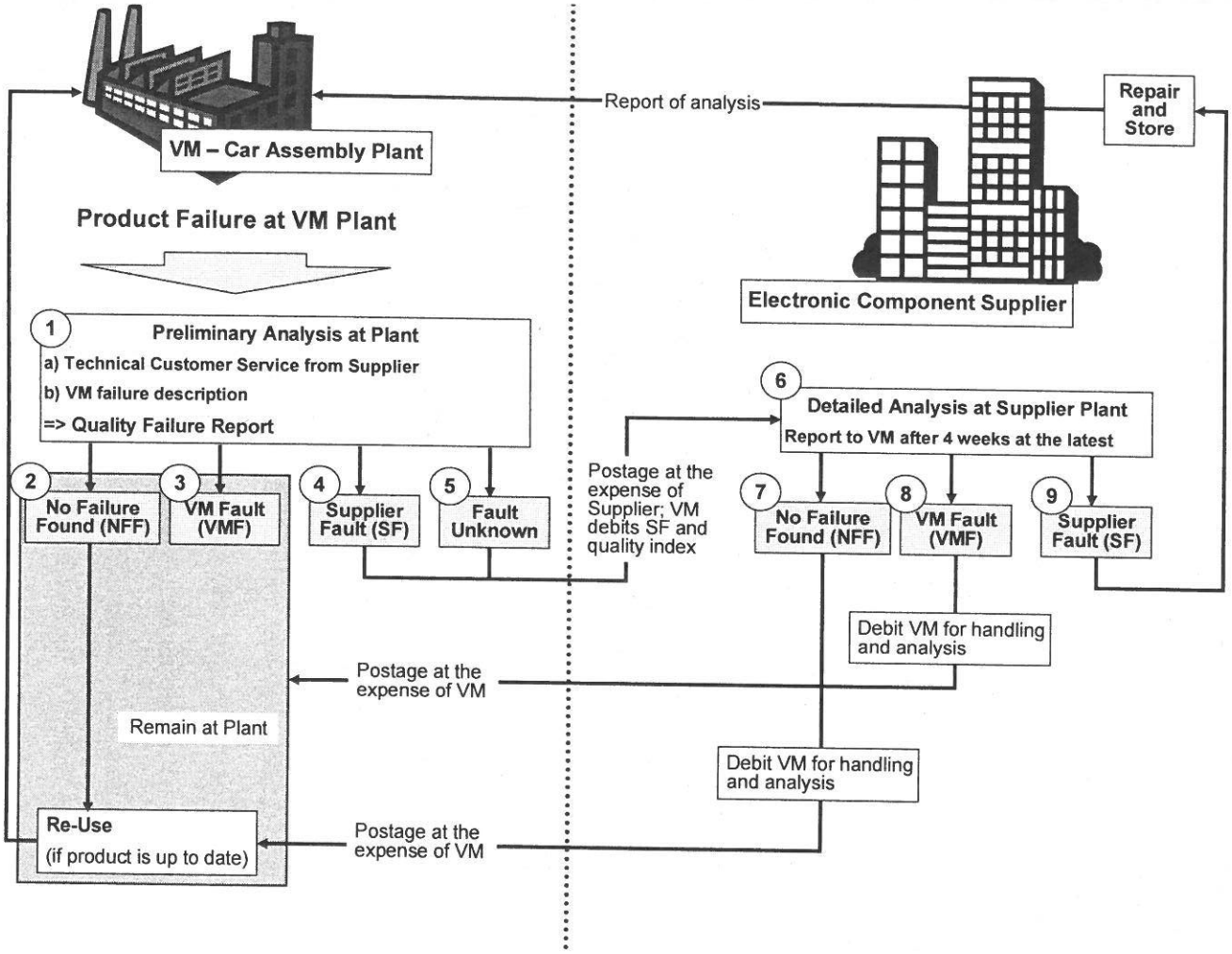


Figure 23: Process Flows of Zero-Mile Product Returns

(Source: reproduced and slightly adapted from documentation by Case Company D; extended by interview data)

Zero-Mile Returns in the Case Company

Within Case Company D, failure identification, return processes and financial flows proceeded in the following sequences. In the case of a zero-mile product failure (point number 1 in Figure 23), a preliminary failure analysis of the device was undertaken by the supplier's technicians. This analysis took place in the vehicle assembly plant. For more complex products, such as cockpit management systems, the supplier may have provided one resident engineer. Further engineers were only required if the supplier also provided assembly and installation services on site, as it is often carried out with car doors or seats.[47]

The faulty devices were classified into the four failure categories: no failure found (NFF), vehicle manufacturer fault (VMF), the supplier fault (SF) and unknown faults (points 2 to 5 in Figure 23). In the case of a supplier fault, the supplier with the system responsibility handled the return process and had to claim compensation from the supplier, whose module caused the defect. However, due to the complexity of zero-mile-return processes, the author renounces to elaborate on this in detail.

Within Case Company D, NFF products remained at the vehicle assembly plant and may have been fed directly back into the assembly process, if they were up to date with the products from the current line. A fault that was caused within the vehicle manufacturer's assembly plant (VMF, number 3 in the above graph) was entirely credited to the car manufacturer. These devices remained at the production plant. Depending on the arrangement between supplier and the vehicle manufacturer, the supplier may have acted as repair service provider by correcting the faults. Repaired devices were then returned to the car assembly plant and installed into vehicles. Errors caused by the electronic device manufacturer (SF, point 4), as well as devices where no error could be identified (point 5), returned to the supplier's plant to undergo a detailed analysis.[48]

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[47] If no resident technician was present at the vehicle assembly plant, Company D's technician would have paid frequent visits (between one and four weeks) to the vehicle assembly plant for a preliminary analysis of product defects.

[48] Usually, electronics suppliers are in possession of superior auditing equipment. Defects which can not be identified in the vehicle assembly plant may be discovered on the premises of the suppliers.

For every SF, the vehicle manufacturer debited the costs to the supplier. Furthermore, each faulty device degraded the supplier's quality index, which is recorded by the vehicle manufacturer. Devices with unknown defects were thoroughly analysed and then categorised into three groups, NFF, VMF and SF defects (point 7 to 9). A detailed analysis had to be completed within four weeks after receipt of the devices from the vehicle manufacturer's assembly plant. If the electronics manufacturer required more than four weeks to detect the defects, the vehicle manufacturer automatically assumed the faults were caused by the supplier and debited the supplier's account as well as the quality record.

NFF devices (point 7) returned to the car assembly plant for direct fitting into vehicles. VMF parts (point 8) were taken back to the assembly plant, since the vehicle manufacturer only refunded VMF devices, which physically returned to the assembly plant. In both cases (NFF and VMF), the vehicle manufacturer was charged for postage, product failure analysis and handling. SF devices were debited to the supplier. These products were repaired within the supplier's repair centres, stored and some of the products may have been sold to the vehicle manufacturer for installation into cars. In other cases, the products were scrapped or remanufactured. Thereafter, the supplier reported to the vehicle manufacturer (product failure analysis). Within this analysis, the supplier explained why the products had been defective and how these defects may be avoided in future. As an example, printed circuit boards may have failed due to inadequate soldering. A potential action of prevention could be additional visual inspection.

From the supplier's point of view, the most inexpensive solution to compensate warranty claims has been the so-called 'hand-over-hand' solution, as recommended by German law. It requires that the supplier provides compensation for the exact number of faulty products. From a legal perspective, electronics suppliers have the opportunity to repair the devices. This 'hand-over-hand' solution may be applicable for smaller parts, such as electronic devices, which can be transported in large numbers. For larger or heavy parts, logistics costs increase. However, within supplying Company D, amendments and repair of faulty devices (hand-over-hand) has proven to be too time

consuming. One interviewee therefore explained that instead of repairing these devices, they were remanufactured, which included, in addition to the repair process, the exchange of wear-and-tear parts.

Field Returns within the Case Company

As opposed to zero-mile returns, field returns were characterised by the fact that the car has left the assembly plant. Field returns were more costly and more difficult to handle for both parties, the vehicle manufacturer and the supplier. Taking the example of a head unit, Figure 24 shows the financial, logistical and informational flows in the case of a field return (Company D).

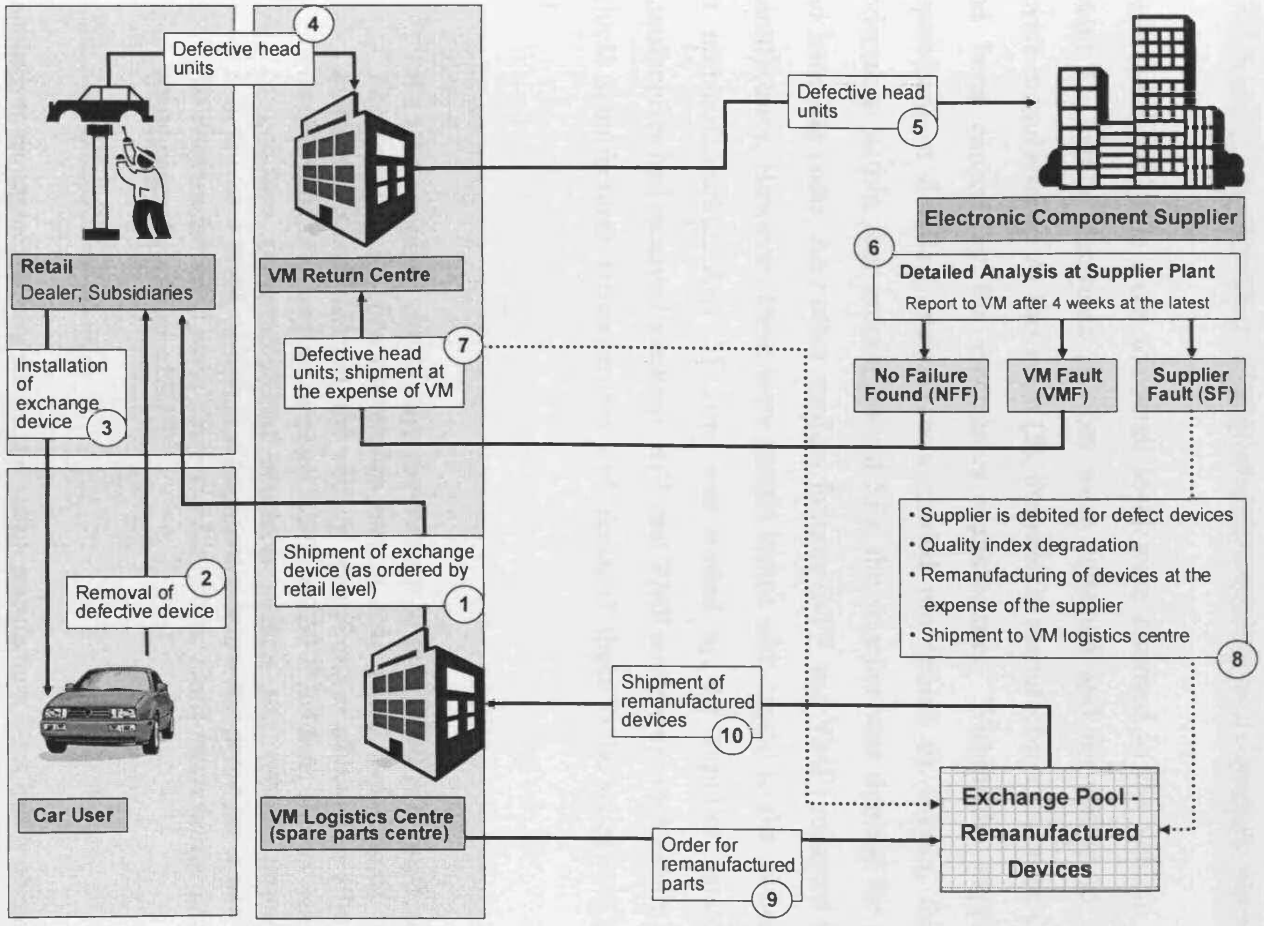


Figure 24: Process Flows of Field Returns for Head Units

(Source: adapted from documentation by Case Company D; extended by interview data)

At the time of the research, a field return exchange took place in the following sequences. The customer approached a subsidiary or a franchised dealer with a defective device. The retailer ordered a replacement which was installed into the car (point 1, 2 and 3 in Figure 24). In the case of a NFF, VMF or SF fault of a board management device, the replacement always consisted of a remanufactured exchange unit.[49]

Defective head units from the retail level were returned to the vehicle manufacturer (point 4). Faulty electronic devices were collected and forwarded to the electronic device manufacturer. At this point (5), the vehicle manufacturer assumed that all defects had been caused by the electronics manufacturer. Within the supplier's quality department, a detailed analysis was carried out (point 6). Again, this had to be undertaken within four weeks. For all SFs, the supplier was debited for product price and handling costs. Any other product failures (NFF and VMF) returned to the vehicle manufacturer. However, there were certain issues with regard to the ownership of cores for remanufacturing. Any SF core was owned by the supplier, since the vehicle manufacturer had received a refund. NFF and VMF cores were technically owned by the vehicle manufacturer. However, the VM 'donated' these to the supplier (Case Company D).

> *We* [the supplier] *are always the owners of the (final) remanufactured product. The transfer of core ownership has to take place beforehand. However, for matters of simplification, the vehicle manufacturer donates us* [the supplier] *the used products emerging through VMF and NFF for free. In this way, we are able to produce remanufactured products, which the vehicle manufacturer can procure at a price, which is significantly below the price for a new part. Orders for remanufactured parts come via Electronic Data Interchange and the delivery takes place by means of SAP.*[50]

[49] Similarly to the engine warranty process, the vehicle manufacturer is not legally obliged to provide the car owner with a brand-new product. In most cases, the customer receives – unknowingly - a remanufactured product. This is profitable for both, the supplier and vehicle manufacturer. Given a SF, the vehicle manufacturer receives a refund from the supplier, due to a faulty device. On the other hand, the electronic component supplier remanufactures the product and sells it back to the vehicle manufacturer. An exception is the beginning of an exchange cycle. In the case of a very new car model, remanufactured products may not yet be available and the replacement may be a brand-new device. As soon as devices are returned and remanufactured, the car user receives a recovered device.

[50] Quoted from personal communication (E-Mail) with the Manager Repair/Remanufacturing Services at case Company D, September 2003, translated from German.

However, for the vehicle manufacturer (Case Company B), there were two different ways of dealing with the ownership of electronic cores. Firstly, there were electronic suppliers, who purchased all (VMF and NFF) cores from the vehicle manufacturer. Secondly, there were suppliers, who did not purchase any cores from the vehicle manufacturer. However, they owned the cores, which were removed due to their manufacturing errors (SFs). Taking the example of two suppliers, the supplier who purchased the cores sold the remanufactured products (to the vehicle manufacturer) for approximately 80% of a new product's price, whereas the second supplier, who did not purchase the cores, charged between 60 and 70% of a new product's price.

7.6 Remanufacturing of Electronic Devices: VM Perspective

7.6.1 Reverse Logistics of Electronic Devices

Similar to the engine core collection, the vehicle manufacturer made use of the extensive network of retailers, distribution centres, and service partners to collect electronic cores. The collection process began when the car owner needed to replace the electronic unit. The retailer placed the component in a special box provided by the vehicle manufacturer. Retailers differentiated between lattice boxes ('nestings') for engines, plastic boxes for electronics, and special boxes for recyclable materials. Remanufacturable components, such as navigation systems, radios, CD-players and head units, were collected by a fast-delivery mailing company (UPS) in Germany.[51] All other components followed the same route to the distribution centres, as it was the case with engines. Radios, navigation systems and head units were directly delivered to a service provider, called ServiceTech in the following.[52]

[51] In December 2002, approximately 200 products were returned from the retail level. This figure was seen as monthly average at the time of the research.

[52] ServiceTech was a company that used to be fully owned by the vehicle manufacturer. The company had been Company B's electronics research and development centre. As outlined in Chapter Five, particularly in the 1990s, vehicle manufacturers have outsourced their captive electronics suppliers. According to interviewees, ServiceTech was seen as unprofitable and lacked in innovation, since there was no exposure to market pressure. In 2003, ServiceTech's tasks mainly comprised consulting work for Company B and other customers, with a focus on production line optimisation.

Hence, components collected by UPS comprised those which had failed functionally and where the manufacturing error causing the failure was unknown. The collection from the retail level to ServiceTech via a fast-delivery ensured that products were returned to the vehicle assembly plant and to the electronic component supplier for quick inspection. Devices for which the reason for product failure had been identified, were directly transported to the supplier for remanufacturing. As previously noted, field returns were by far the most costly type of product return.

ServiceTech sorted the components and delivered these to the vehicle assembly plant. By arrival at the vehicle assembly plant, the electronic components were tested for manufacturing errors, in order to provide an information feedback for the production line. The vehicle manufacturer's employees, as well as the supplier's technicians examined the products.

Several interviewees expressed concerns regarding this examination process, since the vehicle manufacturer lost some of the control regarding the true amount of faulty products. For every product with a pure manufacturing error, there would be a refund by the supplier. However, since the investigation about the true rate of warranty claims made for defective parts was partly executed by the producer of the part, there was a certain amount of suspicion amongst the vehicle manufacturer's employees. The team-leader stated in the interview:

> *Mechanical remanufacturing (e.g. engines, clutches) is totally different from electronic remanufacturing. Within mechanical remanufacturing, all process steps are clearly defined. On the other hand, our knowledge about electronic remanufacturing is at the total beginning. We can ask suppliers for everything, but we cannot control, verify or check anything. Suppliers just name a price and we have to accept it. The process is absolutely not traceable. Do the suppliers replace a part or do they just repair it – who knows?*[53]

[53] Quoted from the interview with the Team Leader for Stock and Supplier Management Electronics at Case Company B's Global Warehouse, February 2003, translated from German.

7.6.2 The Remanufacturing Echelon of the Closed-Loop Supply Chain

In the course of the research, the facilities of two electronics suppliers, Company C and D were visited. Company C had outsourced most of its remanufacturing activities to a subcontractor. However, a few work stations remained at the production plant for information feedback to the assembly line. This electronics producer supplied most of the well-known vehicle manufacturers with products, often just with amplifiers. According to the main interviewee at Company C, a radio or navigation system consisted of 400 to 500 parts which were supplied by more than 200 different component manufacturers.

The observation within the production plant for new goods demonstrated that the high-volume electronic device production process was largely automated in the beginning, in which circuit boards were equipped with components. Later in the process, more manual work was required, when employees assembled the main modules of the devices. Similarly to the engine remanufacturing process, electronic device remanufacturing was far less automated and had been undertaken at single workstations. The identification of the cause for product failure accounted for the largest part of the remanufacturing throughput time.

At the time of the research, Company C remanufactured devices for three major car producers. Compared to a daily production volume of 1,800 radios and head units manufactured in the plant, just about 90 devices per day were remanufactured by seven workers (for Vehicle Manufacturer B). According to the interviewee, throughput times in electronics remanufacturing have always been high. This was particularly due to the extensive warranty adjustment process, in which the source of a defect had to be found.[54]

[54] For a more extensive discussion on the role of the warranty adjustment process, please refer to Appendix L.

In a combination of the processes investigated at Company C and Company D, the following electronic device remanufacturing process could be established. It has to be noted that process observation ('walking the process'), as it was undertaken in the engine case study could not be completely carried out, since many of the processes could not be visually followed. The following Figure 25 was therefore mainly based on interviews.

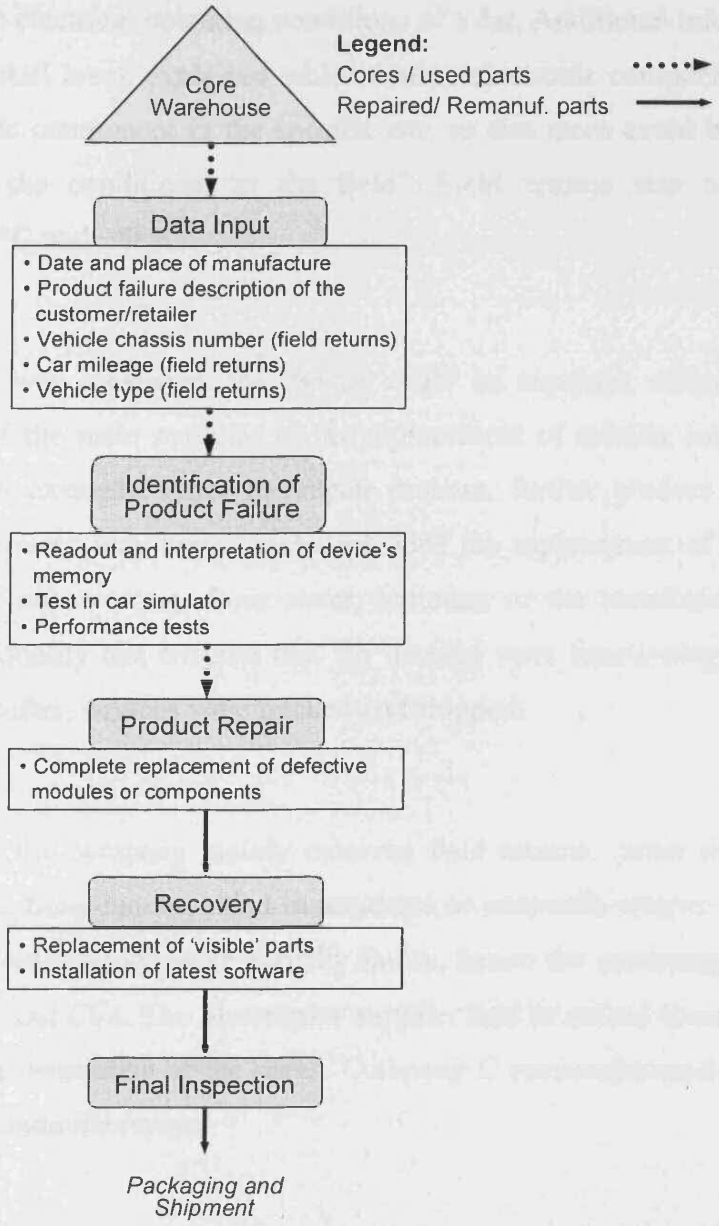


Figure 25: Electronic Device Remanufacturing Process

The overall process comprised the following steps. The product characteristics, such as the date and place of manufacture, the product failure description of the customer, the chassis number (field returns), the mileage (field returns), as well as the vehicle type (field returns) were entered into a database.

Thereafter the cause for the product failure had to be identified. This could have been discovered by the readout and interpretation of the device's failure memory. Moreover, operational test in a car simulator were undertaken. During this inspection process, employees simulated the electrical operating conditions of a car. Additional information, often provided by the retail level, explained which further electronic components were attached to the electronic component in the specific car, so that there could be a case-specific simulation of the conditions 'in the field'. Field returns also underwent performance tests in -40°C and +85°C.

Once the product fault was identified, the device could be repaired, either through complete replacement of the main modules or the replacement of smaller components on the circuit board, for example. After the repair process, further product recovery processes followed. Recovery may have hereby included the replacement of parts the customer could visually observe (e.g. front cover, buttons), or the installation of the latest software. A final quality test ensured that the devices were functioning and met the quality targets. Thereafter, devices were packed and shipped.

Supplier C claimed that the company mainly received field returns, rather than cores from end-of-life vehicles, from cars involved in accidents or zero-mile returns. Between 50% and 70% of the cores returned were actually faulty, hence the percentage of SFs seemed to exceed NFFs and CFs. The electronics supplier had to refund these devices and thereby acquired the ownership of the cores. Company C remanufactured and sold these back to the vehicle manufacturers.

With regard to the quality criteria, all interviewees confirmed that remanufactured devices were considered equally to new products, as it is the case with car engines. However, there were two factors which are very different between engine and electronic

device remanufacturing. As previously noted, engine remanufacturing could be visually followed, whereas electronics remanufacturing has been less comprehensible to the layman. Secondly, one of the main reasons why suppliers and vehicle manufacturers have taken up electronics remanufacturing was the fact that within the warranty adjustment process, the cause for product failure had to be identified, which was perceived as the most time-consuming activity in the above remanufacturing process. Compared to that, the repair and remanufacturing steps were small 'follow-up' processes of the failure identification.

7.6.3 Issues within the Electronics Closed-Loop Supply Chain

Although the vehicle manufacturer (Company B) feared system loss regarding cores, no particular countermeasures were undertaken by the group. According to one interviewee, the rebate should have motivated the retail level sufficiently enough to make the reverse logistics network successful.

> *If the rebate is too low, there is a migration of cores to the independent market. Other than the rebate, there is no control over cores, in other words, outside our distribution channels and dealer networks, we cannot do anything to avoid system loss. But I would assume that system loss is no problem regarding electronic components. These products are just too complex and cannot be remanufactured easily. Furthermore, the only advantage the independents have is the low wage level and therefore their prices for the products are lower. However, the only real competitors in the market for remanufactured electronics are our own suppliers.*[55]

Supplier D's aftermarket expert assumed that vehicle manufacturers had recognised strong competition from independent remanufacturers. However, from his point of view the VMs still seemed to believe in their predominant role in the market.

[55] Quoted from the interview with the Manager Stock and Supplier Management for Special Tools at Company B's Global Warehouse, February 2003, translated from German.

> *European vehicle manufacturers are very arrogant. They think, if customers receive a rebate for the used products, they will all return these to the vehicle manufacturer. The reality is different. BMW, for example, had planned to remanufacture 80% of a certain product and in the end they remanufactured 20%, since no cores were available. The reason for that is that independent core-brokers skim off all cores; vehicle manufacturers do not know anything about the market and this is the main issue. In the United States, a well-established market for remanufactured products, there are core-brokers with a lot of contacts and experience. The European vehicle manufacturers, however, do not know the market.*[56]

The second issue, which has been briefly discussed in the previous chapter, was the problem of 'unequal exchange'. The unequal exchange indicates that the customer ordered a device from a recent generation and hands back a very old unit. Within the engine remanufacturing cycle, this issue has been less relevant, due to the fact that later engine generations may often not be fitted within previous cars generations.

In the electronics sector, the unequal exchange is a particular issue with regard to radios and CD-players. The downward compatibility of devices and software usually facilitates this type of exchange. However, the unequal exchange is costly for the VM who receives an outdated core and loses an 'as good as new' device. Vehicle Manufacturer B therefore decided not to support unequal exchanges.

> *The availability of remanufactured electronic products, such as radios, CD-players, and mobile phones depends entirely on your* [i.e. retailer] *behaviour of sending back the cores to us* [VM]. *An unequal exchange, as it is often the case with radios, will not be subsidised by the group any longer.*
>
> (Company A/B, 2000, p.A2)

A third issue, which had been noted previously, was the mistrust between the VM and the suppliers with regard to the warranty adjustment process. However, in course of the research, it became clear that not just the warranty adjustment process seemed to be a critical factor, but interviewees also expressed that, with regard to remanufacturing, the VM would depend too strongly on the suppliers. Chapter Five has already discussed the

[56] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at case Company D, July 2003. Translated from German, partially cited in Seitz and Peattie (2004).

power relationships in the automotive supply chain and the trends towards more responsibility for the suppliers. Within the case study on electronic device remanufacturing, this had been proven to be disadvantageous for the VM.

A good case in point was the question of software ownership for navigation systems and head units, which was installed onto the devices by the supplier, but owned by the vehicle manufacturer. According to Company B's electronics team leader, the vehicle manufacturer discovered that one of their suppliers used this software to equip its own remanufactured products without the vehicle manufacturer's permission. As a result, some interviewees expressed certain mistrust with regard to suppliers.

> *Officially, electronics suppliers do not market remanufactured products via their distribution channels. But there is always the danger that they do, particularly if they have well-working distribution channels and offer a wide range of products on the aftermarket. It is therefore very suspicious, if they claim that there was a huge increase in the percentage of new parts added to the remanufacturing process, which they carry out for us. If the suppliers then increase our purchasing prices for remanufactured products due to the increase of new and expensive parts, we have to have a closer look at their business processes, which is usually done by our service provider.*[57]

According to this interviewee, controlling the suppliers' remanufacturing activities has not been easy. This was due to technical transformations within the remanufacturing process, which complicated the traceability of devices. In fact, electronic devices may have been transformed into upgraded variants during remanufacturing. As a result the routes of products have become untraceable, since they also received new identification numbers. Hence, part numbers of cores did not necessarily match the remanufacturing output.

[57] Quoted from the interview with the Manager for Stock and Supplier Management of electronic devices and project manager of the electronic device remanufacturing project at case Company B's Global Warehouse, February 2003, translated from German.

The fourth issue within the closed-loop supply chain for remanufactured electronic devices was related to the traceability of devices as just outlined. Although product proliferation has been identified as a much stronger issue within car engine remanufacturing, technical changes seemed to take places much more rapidly in the electronics sector. Interviewees explained that every change in the hardware of a product lead to a blockade in the remanufacturing cycle. Every major change in the product resulted in a new variant with a new product number. These changes had usually incorporated improvements with regard to quality. Consequently, not necessarily new product variants were created, but new quality levels were achieved.

From an aftermarket perspective, this meant a large amount of different product generations. As an example, one of Company B's ECUs had been changed 18 times between its creation (2000) and the year of the author's observation (2003).

It may be concluded that although technical changes occurred more often and more rapidly in the electronics segment, they did not impose limitations or obstacles onto the remanufacturing process. This is due to the fact that electronics remanufacturing was undertaken in an environment which resembled a 'handcraft' type of production, with one worker remanufacturing one device at a time. As opposed to that, within engine remanufacturing, the Case Company had sought to replicate mainstream engine manufacturing, characterised by the total disassembly of an engine and workers recovering parts instead of the whole product. Within electronics remanufacturing, however, the craft production system proved to be very flexible, with regard to product variation. This may explain, why none of the interviewees mentioned issues with regard to parts proliferation within electronics remanufacturing.

7.7 Generic Issues and Observations – Electronics

Similar to the summary in Chapter Six, Table 49 matches the generic issues and obstacles that were identified in Chapter Two with the specific case study findings for electronic device remanufacturing. Table 50 adds further aspects that were discovered within the specific case of electronic device remanufacturing and outlines current industry practice.

	Generic Issue/Problem Area	Observation/Current Industry Practice
Issues Identified in the Literature	Collection structure complexity	▪ The vehicle manufacturer's forward distribution system is used for core collection ▪ Complexity is higher than for engines, since cores have to be delivered to suppliers ▪ Remanufactured products are supplied by the first tier and distributed through the VM route
	Integration of forward and reverse flows	▪ Additional complexity due to the integration of the VMs and the supplier's collection and distribution systems (as shown in Figures 23 and 24) ▪ System is less developed due to short history of electronic device remanufacturing ▪ Complexity increases due to a number of module producers involved ▪ Remanufacturing as a part of the warranty adjustment process
	Complex inventory management	▪ Company D has expressed no issues with inventory management ▪ Products may be less difficult to handle than engines, due to reduced weight and size
	Finding markets for remanufactured products	▪ Not an issue for electronic devices; many of the products are under-warranty replacements
	Uncertainty in timing and quantity of returns	▪ Faster return processes than for engines (e.g. return via UPS); also due to warranty adjustment process requirements ▪ Time frame between new production and core return for remanufacturing is shorter than for engines; forecasting may therefore be more reliable
	Uncertainty in quality of returns	▪ Product failure often not visible
	Product disassembly	▪ May not take place as such ▪ Product defect may be eliminated through the application of new software
	Design for remanufacturing	▪ Standard requirement in contracts between the VM and the supplier; in reality, design for environment not always considered

Table 49: Matching Generic Issues in the Literature with Case Study Observations – Part 3

	Generic Issue/Problem Area	Observation/Current Industry Practice
New Observations	Core collection and product exchange	▪ Competition for cores from the independent sector increases with this sector's growing interest in electronic device remanufacturing ▪ Vehicle manufacturers and their suppliers compete for cores ▪ Problem of 'unequal exchange' is more significant than for engines, due to downward compatibility of devices and software ▪ Competition from the supplier base who distributed remanufactured devices through their own channels
	Remanufacturing process	▪ High remanufacturing throughput times due to extensive warranty adjustment process (identification of the cause for product failure) ▪ Difficult to comprehend, since many processes cannot be visually observed ▪ Mistrust between vehicle manufacturer and supplier with regard to warranty adjustment and remanufacturing process (lack of traceability of devices)
	Product complexity and proliferation	▪ Electronic device consists of 400 to 500 parts, which are supplied by more than 200 companies ▪ Warranty adjustment and remanufacturing is more complex due to several module suppliers involved in the production of a head unit, for example ▪ Technical changes taking place more rapidly than within engine sector but do not provide obstacles for the 'craft remanufacturing' system
	Spare parts supply	▪ Option to combine repair, re-use, remanufacturing and redesign to secure spare parts over decades ▪ Increasing costs if 'design for remanufacturing' approach is not considered ▪ Post-serial supply is critical for electronics that are fundamental to the operation of a car; less critical for entertainment units

Table 50: Matching Generic Issues in the Literature with Case Study Observations – Part 4

7.8 Conclusion

This chapter has presented the results of the second major case study within this research. It has firstly outlined the specific characteristics of electronic components in cars. Due to conflicting product life cycles of cars and semiconductors, concerns with regard to the long-term supply of electronic devices have evolved among vehicle manufacturers. Although remanufacturing represents just one of many strategies to secure spare parts supply in the automotive sector, its importance is expected to increase with the increase of electronics in cars. The first part of the chapter has therefore introduced the reader to this relatively new type of remanufacturing, but hereby also emphasised the major differences between mechanical and electronic remanufacturing.

The second part of the chapter has illustrated the diversity of reverse flows from the supplier's perspective at the time of the research. It has shown that due to the involvement of the supplier, reverse logistics flows and the distribution of remanufactured devices is more complex for electronics than it is for engines. Due to the short history of electronic device remanufacturing the establishment and management of the closed-loop supply chain was at an early stage. Issues between closed-loop supply chain members included the mistrust between the vehicle manufacturer and the suppliers (lack of traceability of devices) as well as competition for cores.

This chapter represented the second link between the Research Questions 1 and 2 for a specific case on electronic device remanufacturing and the discussion of these in Chapter Nine. It has demonstrated that remanufacturing operations, even for products that find application in the same industry, can be significantly different. Hence, generalisations, as they are often made in the literature, should be made with care.

Moreover, the chapter has presented different motives for electronics remanufacturing than there were for engine remanufacturing. These will be discussed and compared in Chapter Ten in more detail.

Chapter Eight
The European Remanufacturing Sector: A Survey

8.1 Introduction

This chapter highlights the results of a questionnaire survey undertaken at the automotive remanufacturing trade fair 'ReMaTec 2003', a European trade fair for automotive remanufacturers, their suppliers and customers. Around 180 companies exhibited and promoted their services and products at ReMaTec 2003 in Amsterdam, The Netherlands. The main purpose of the questionnaire survey was to test, validate and generalise the research findings from the in-depth case study research.

Besides undertaking the survey, there was the possibility for discussions and interviews with exhibitors, industry experts and visitors of the trade fair. Supplementary information on remanufacturing (e.g. brochures and catalogues) was obtained in order to complement and enrich the data collected at the event.

The exhibition was supported by two of the major international associations, the APRA (*Automotive Parts and Rebuilders Association*) and the FIRM (*Federation Internationale des Rectifieurs et Reconstructeurs de Moteurs*). Both of the organisations hosted workshops and seminars alongside the event. Several workshops were attended

by the author, in which industry-specific and in-depth information was obtained. In one particular APRA meeting, members, APRA directors and further industry experts, such as Professor Rolf Steinhilper from the University of Bayreuth, Germany, discussed APRA's idea of creating a subdivision for electronics remanufacturing.

The questionnaire survey itself focused on exhibitors to the event, including remanufacturers, distributors, and producers of new parts. The survey was not undertaken in isolation, but within the context of initial findings and observations from the previous phases of the research. The survey's aim therefore evolved around the extension, verification and generalisation of the case study research. It was expected that the questionnaire would provide further insights into the remanufacturing industry, but particularly into the practices of independent remanufacturers. Through the review of previous surveys, this chapter also demonstrates that the automotive remanufacturing industry is a sector for which little factual information exists.

8.2 Surveys on (Automotive) Remanufacturing

Three surveys that are relevant to this dissertation have been undertaken by previous contributors. One survey focused on the automotive sector (Hammond *et al.*, 1998) and two have investigated remanufacturing in general (Lund, 1996; Guide, 2000). None of them was undertaken in Europe. The survey presented in this chapter takes a European perspective, however, no European survey on remanufacturing could be found for comparison. The lack of descriptive data on the European automotive remanufacturing sector was also confirmed by Oliver Schulz, one of the show's organisers.

> *I am giving your proposal serious considerations as this topic obviously interests me – but also because the theoretical research so far has been limited when it comes to automotive remanufacturing in Europe.*[58]

[58] Quoted from personal communication (E-Mail) with Oliver Schulz, one of the ReMaTec trade fair's organisers located in Berlin, Germany, January 2003.

Lund (1996) has surveyed a random sample of over one thousand American remanufacturers in order to identify and characterise the industry. He provides information on a large numbers of industry sectors including automotive, compressors, electrical apparatus, office furniture, toner cartridges and tyres. One of his main objectives was to create a database of all remanufacturers to characterise the structure and size of the industry and to define the needs of the sector. His report was probably one of the first attempts to collect and record data on the remanufacturing industry on a large scale. Main findings relevant to this research include the fact that the average company employment of the remanufacturing industry was estimated to be 24 (in 1996).[59] The 4536 automotive companies in the survey had between one and 1819 employees (with a mean of 29.4). Hence, Lund's work summarises and identifies the characteristics of a typical American remanufacturing company.

A more extensive study has been conducted by Guide (2000) (see also Guide *et al.*, 1999). According to Guide, this survey "never intended to be a stand-alone research piece, but rather to serve as empirical grounding for modeling parameters" (Guide, 2003). This survey consisted of 75 questions, which covered seven areas: general company information, demand management, materials management, production planning and control, as well as further information. The response rate was 15% (48 useable surveys). Responding remanufacturing companies included automotive companies (33%), aerospace, machinery and office equipment, and others. The survey's main findings comprised an indication of the company's manufacturing strategies (make-to-stock, make-to-order or assemble-to-order), as well as the determination of complicating characteristics within remanufacturing operations. However, it still has to be noted that the research by Guide took a rather narrow in-plant remanufacturing perspective.

The third piece of work by Hammond *et al.* (1998) has focused on the US automotive sector. Similar to the objectives pursued by Guide (2000), the survey by Hammond *et al.* (1998) aimed at the identification and verification of obstacles that remanufacturing

[59] The 2003 report by Hauser and Lund (2003) still refers to the figures from 1996.

companies are facing. Hammond *et al.* (1998) carried out three surveys. The first survey provided insights into key concerns expressed by remanufacturers in open-ended questions. The second survey, a follow-up questionnaire, aimed at a more detailed understanding of the issues expressed in the first survey. In the third survey, the respondents weighted the key issues from the first two surveys. The major findings which were discovered by Hammond *et al.* (1998) demonstrate, that one of the major threats to the independent remanufacturing sector is the fast pace in modern production practices from original equipment manufacturers, such as metrics and design changes ('parts proliferation').

In all three pieces of work, the independent sector has played a dominant role. The work by Hammond *et al.* (1998) focused entirely on independent remanufacturing and Guide (2000) reports that the respondents to his survey have largely been non-OEMs (95%). Lund (1996) does not indicate the share of OEMs within responding companies, but the particularly small average of employees seems to indicate that many of these companies were independents or even run by part-time entrepreneurs. This has been confirmed in Lund's later work, in which it became clear that "where OEMs participate, they are among the largest remanufacturers in terms of both sales and employment" (Lund in Schwarck, 2003a, p.14).

8.3 Questionnaire Design

According to Amezquita *et al.* (1995), OEMs do not perceive remanufacturing as a core activity and most of the remanufacturing activities are performed by third party remanufacturers. However, the authors further claim that more and more original manufacturers are becoming involved in the remanufacturing of their own parts and components. OEM remanufacturing has been intensively discussed in Chapters Six and Chapter Seven of this thesis. This chapter also considers automotive remanufacturing undertaken by independent players in the market and therefore extends the case study research.

The results displayed in this chapter do not focus on one particular product group, but on automotive remanufacturing in general. The ReMaTec 2003 trade fair was selected

as location for data collection. This had two advantages. Firstly, the trade fair was not limited to one particular group of automotive remanufacturers. Secondly, as briefly outlined in Chapter Four, a high quality of responses was expected, since the questionnaire was administered by the author, so that misunderstandings or ambiguities which may have occurred during the interviews could be clarified immediately. This aspect also stressed the need for a short and understandable questionnaire design. Compared to a mail questionnaire, response bias could therefore be decreased. In addition, the quality of responses was increased, since exhibitors were perceived to be amongst the most innovative and interested players in the market, which they demonstrated by exhibiting at this event, by attending workshops and seminars and by exchanging ideas with partners and competitors. It could therefore be claimed that attending companies were more likely to be professional, active and well informed about the sector, which increased the validity of the questionnaire findings.

Purpose of the Questionnaire

As briefly noted in Chapter Four, the questionnaire survey had several purposes. Firstly, it aimed to test the generic assumptions from the literature and the findings from the in-depth case study research. In this way, the results from the preceding research (Chapters Six and Seven) could be cross-examined. As an example, the motives for product take back and recovery that were identified in Chapter Three (e.g. legislation or corporate social responsibility) were questioned with regard to their applicability to other product groups and players. The idea of testing and validating research results is also a part of the theory building-process as outlined in Section 3.2.1. Keating (1995) claims that a theory is a set of statements that is valid after being tested throughout a number of cases. With regard to this thesis, the objective was to develop elements for a closed-loop supply chain theory. Therefore, the testing and validation of research results is a significant part of the research process.

The second purpose of the questionnaire refers to the 'hourglass notion of research', as recommended by Trochim (2003). The structure of research he recommends resembles an hourglass by beginning with a broad research question. The research is thereafter narrowed down, but broadened towards the end (Trochim, 2003). This research has followed the structure recommended by Trochim. The questionnaire survey sought to

complement the OEM perspective, which was adopted within the in-depth case study research, by the perspectives of other players in the market, such as the subcontracted and the independent remanufacturers. This also increased the validity and generalisability of the findings, since the case study results were tested on different types of companies and product groups.

The questionnaire's purpose was not to prove a statistical significance of an observed phenomenon, but to discover and validate similar, emerging trends throughout the automotive remanufacturing sector. Since the remanufacturing sector is generally perceived as dispersed, complex and difficult to access (see, for example, Hauser and Lund, 2003), the European automotive remanufacturing trade fair ReMaTec provided an opportunity to test and validate the case study results.

Oppenheim (1992) emphasises that there is the need to pilot the questionnaire before the survey is conducted. This helps to improve the wording of questions, procedural matters as well as the order of questions. Piloting the questionnaire proved to be difficult, as the questionnaire's sample (the trade fair's exhibitors) was unknown to the author. Since it was planned that the questionnaire would be administered by the author, the main emphasis was put on the question wording and content, rather than the questionnaire's layout. The questionnaire was discussed with a variety of academics, including a statistician and three automotive experts. Valuable comments were made by the local parts retailers, who kindly completed the questionnaire. The questionnaire applied within this research can be found in Appendix M.

Composition of Questions

The questionnaire comprised eleven questions (as shown in Appendix M). The aim was to create a short questionnaire with a simple structure, which could be completed in a short period of time.

The first five questions investigated general company information. Question Six asked for the type of products being remanufactured at the respondent's facility. Seven product groups were provided, which are displayed in Appendix N. One more product

group, 'chassis dynamics' was generated during the questionnaire analysis. The reasons for this will be explained in Section 8.4 in more detail.

Questions Seven and Eight of the questionnaire investigated aspects for growth and factors which restrict growth in the market. Respondents were asked to rate up to three aspects, which they found the most significant 'creators' or 'restrictors'. A number of proposed answers were given, however, the question left room for interviewees to express and rate further factors they found most significant. Question Seven, which investigated aspects that respondents believed to create growth in the market, aimed at presenting all driving forces that have been identified in Chapter Three and further motives that resulted from the case study research. However, the author did not wish to provide all answers for the questions, but asked respondents to develop their own ideas. Proposed answers therefore included factors of growth with ethical motivation (environmentally conscious customer; pressure from society), business aspects (increase in demand from distributors, retailers and wholesalers; increase in waste disposal costs), operational factors (easier availability of cores) as well as legal motivators (legislation; extended producer responsibility).

Question Eight, on the other hand aimed at identifying the opposite factors. It asked respondents for the identification of the three most important determinants that restrict growth in the market. Answers had been classified into operational (core availability; achieving economies of scale; product proliferation), market-related (competition from other spare parts; lack of demand), product design related (OEM specifications; design for disposal; longevity of OEM parts) and legal aspects (demands on quality and standards; regulations on the environment or labour). Again, respondents were not restricted to select answers which were suggested by the author, but they could express and rate factors which they felt were more significant.

Question Nine asked the respondents to evaluate the market climate for their particular product group(s). The questionnaire therefore sought to verify the claims made by OEM remanufacturers within the case study research, which included the fact that electronic component remanufacturing was seen as one of the most recent developments in the sector.

The penultimate question (Question Ten) asked for the company's main reason to being involved in the remanufacturing business. The author was aware that this question could only be fully answered by the owner of the business. However, as the results will show, most of the respondents were the companies' managing directors. All other respondents were asked to answer this question on the basis of their industrial experience.

In the last question, the interviewees assessed the change in profitability in the overall remanufacturing sector since the year 2000.

Sampling Frame

Within the context of sampling, the term 'population' is applied for all respondents that fall in the given category of concern (Oppenheim, 1992). In this study, the population comprised all representatives of automotive remanufacturing companies. Chapter Four has outlined that it is very unlikely to ask every member of the population, hence surveys usually comprise a subset of the population, the so-called sample (Zikmund, 1994). Within this research, each individual acted as a representative of the company. The respondents therefore represented the unit of analysis as defined by Zikmund (1994), or the sub-sample as identified by Trochim (2002d). In the course of the questionnaire design process and the pilot study, the question occurred whether the sample of the questionnaire was representative. There were several considerations.

Firstly, the characteristics of the population (European automotive remanufacturers) are difficult to determine. This refers to size and type (OEM, independent or subcontracted), for example. A large number of automotive remanufacturing operations are undertaken as non-core business activities and are therefore difficult to identify, a factor which has been confirmed by Hauser and Lund (2003).

Secondly, the automotive remanufacturing sector is very lively with many small companies that are prone to insolvency. As a result, market data is not only unavailable, but also may become out-of-date rapidly.

Enquiries with industry experts, such as Professor Steinhilper did also not provide a proof for the sample's representativeness. He confirms that there is little research on the European remanufacturing market which would provide this specific information.

> *I do know the American authors* [...], *Professor Lund* [...] *and his first assistant Dr. William Hauser personally* [...]. *Therefore I know that their reports (which I cite myself) were based on the work by a large number of students who have collected data in a timeframe of one to two years. In Europe, we have so far not managed to bring these resources (manpower) together. You know from your own research, what difficulties research on remanufacturing incorporates.*[60]

Ludford (2004) also confirms that factual information on the European remanufacturing industry is rare. Most of it is anecdotal and has been gained through working in the industry. However, for the UK engine remanufacturing sector, he confirms that the sector is characterised by many, rather small businesses.

> *As to the size of these companies it is difficult to say. In our Federation we have some 140 'engine re-manufacturers' of which only about four number of employees over 150. The majority are small firms with, say, 8 to 12 employees.* [...]. *There are about 800 engine re-manufacturers in the UK, but most of these do what is called 'jobbing work' e.g. they may rebuild a cylinder head, they may skim a block etc. There are only a handful of companies that re-manufacture whole engines on any kind of scale. Our association is a member of the European association called FIRM. Speaking to my colleagues there, I suspect that the UK situation is reflected across Europe.*[61]

[60] Quoted from personal communication with Rolf Steinhilper, Professor for Manufacturing and Remanufacturing Technology at the University of Bayreuth, Germany, June 2004.
[61] Quoted from personal communication with Brian Ludford, the General Secretary of the UK Division of the Federation for Engine Re-Manufacturers (FIRM), Plymouth, June 2004.

Analysis

The questionnaire itself was very focused and short with only eleven questions. This also meant facilitated data analysis, which was an important factor within this research, since the preceding case study research had been very time-consuming. The brevity of the questionnaire also increased the willingness of potential respondents to participate in the survey.

As previously outlined, the purpose of the questionnaire was not to prove statistical significance of certain phenomena, but to test previous research findings and to discover similar, emerging ideas across the automotive remanufacturing sector. Consequently, for the analysis of the questions, the cross-tabulation method was applied. Zikmund (1994) describes cross-tabulation as "a technique organizing data by groups, categories, or classes, thus facilitating comparisons; a joint frequency distribution of observations on two or more sets of variables" (p.464). Cross-tabulation may be utilised to examine answers of a single question more closely, for example in order to identify relationships between variables. It furthermore allows discovering relationships between variables of different questions.

8.4 Results[62]

8.4.1 Characterising Responding Companies

Overall, 48 responses were obtained. All of them were usable. A complete list of the companies that participated in the survey can be found in Appendix O. Figure 26 gives an overview of the countries in which the companies were located. All of the respondents were exhibitors at the trade fair.

[62] Due to great interest from the automotive remanufacturing sector, some results of this survey were published in the April/May 2004 issue of the ReMaTec News.

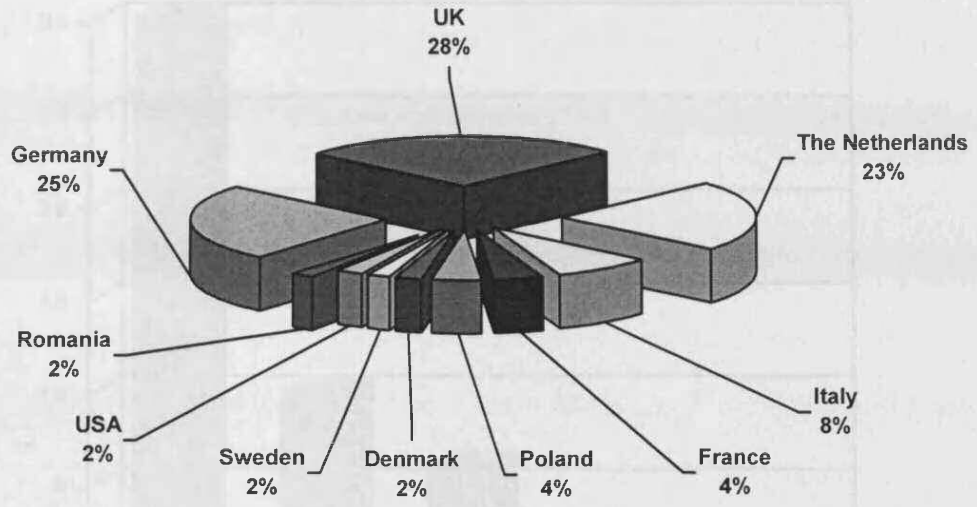


Figure 26: Responding Companies - Countries of Residence (Headquarters)

Overall, there was a strong representation of Western European companies (96%), very few Eastern European remanufacturers (6%) and just one non-European respondent (USA). Within this Western European perspective, companies from the UK dominated with 28% (13 respondents), followed by German (25%) and Dutch (23%) remanufacturers.

The largest proportion of respondents indicated that their company could be described as 'independent remanufacturer' (36 respondents), whereby few of these companies provided services to original equipment manufacturers. Just two respondents described their employer as 'OEM remanufacturer'. Few companies engaged in remanufacturing for their own purpose, but also provided services to other companies (7 respondents). Figure 27 displays the type of companies, which were surveyed at the trade fair.

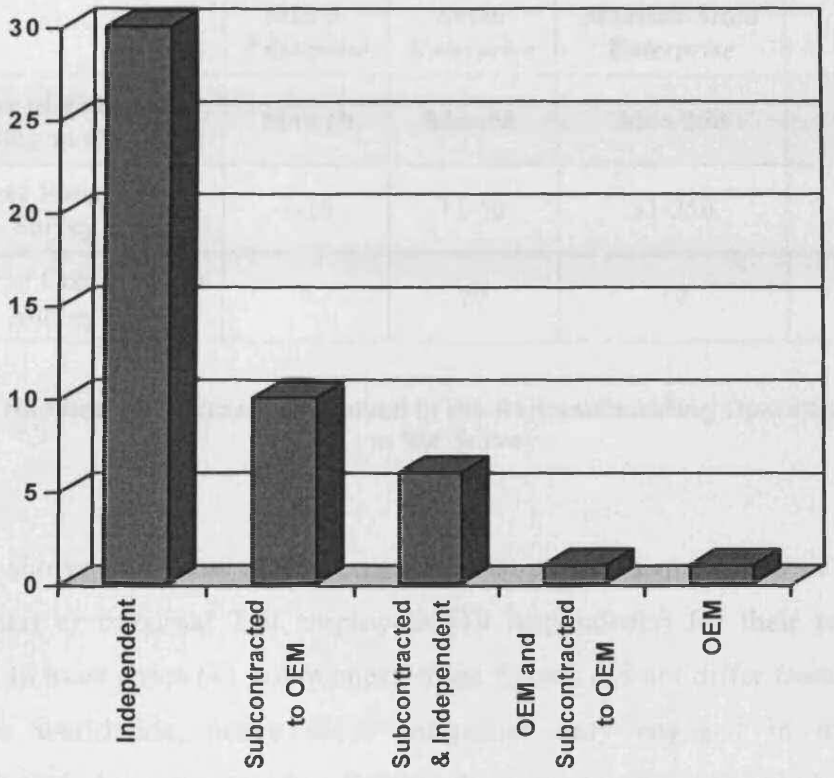


Figure 27: Type of Remanufacturing Business (in absolute figures)

The sizes of the companies differed to a large extent. One responding company, a first-tier automotive supplier, employed 186,000 people worldwide. Other companies had just two employees. The average number of all companies surveyed was 4,595 employees (worldwide), but did not give any details about the actual number of employees involved in remanufacturing. Further analysis therefore focused on the number of employees involved in remanufacturing only. Taking the remanufacturing activity in isolation, the average number of employees involved in remanufacturing within responding companies was 86. However, the following analysis identifies to which extent very large remanufacturers distorted the results.

Most of the companies which had been surveyed fell into the category of the Small and Medium-sized Enterprises (SMEs), as defined by the European Commission (CEC, 2003). The following Table 51 shows the number of people involved in remanufacturing within the companies, categorised by the definition of the European Commission. This definition also incorporates the maximal turnover and the maximum balance-sheet total. However, Table 51 only focuses on the company size.

	Micro-Enterprise	*Small Enterprise*	*Medium-Sized Enterprise*	*Non-SME*
Number of Employees (according to the CEC)	**Max 10**	**Max 50**	**Max 250**	-
Employee Range within Survey	1-10	11-50	51-250	from 251
Number of Companies in Survey	7	20	19	2

Table 51: Number of Employees Involved in the Remanufacturing Operation – Companies in the Survey

Table 37 shows that most of the companies employed a maximum of 50 people (20 respondents) or maximal 250 employees (19 respondents) for their remanufacturing activities. In most cases (41 companies), these figures did not differ from the number of employees worldwide, hence these companies only engaged in remanufacturing operations and did not provide other products or services. Concluding, the largest percentage of companies responding to the questionnaire could be described as Small enterprises or Medium-Sized Enterprises, respectively.

For a more detailed analysis, the cross-tabulation method was applied. In this case, Question Three (the approximate number of employees involved in remanufacturing) was related to Question One (type of company), in order to gain further information on the characteristics of the independent remanufacturing market and its players. Please note that some companies operated in more than one area (Question One), hence the overall number of respondents was 55 rather than 48. Table 52 shows the relationships that could be identified.

	OEM Remanufacturer	Subcontracted to OEM	Independent Remanufacturer
Micro-Enterprise 1-10 Employees	-	-	7
Small Enterprises 11-50 Employees	-	6	15
Medium-Sized Enterprises 51-250 Employees	1	10	13
Non-SME 251+ Employees	1	1	1
Total	**2**	**17**	**36**

Table 52: Number of Employees Involved in Remanufacturing by Company Type

The cross-tabulation analysis indicates that the largest share of independent remanufacturers within this survey consisted of Small or Medium-Sized Enterprises. Remanufacturers which were subcontracted to original equipment manufacturers tended to me rather small, too. This fact confirmed the initial assumption that the independent market is mainly composed of smaller, often family-run businesses with less than 250 employees. This also explained why in many cases, the managing director had attended the trade fair and could be asked for participation in the survey (see Table 53).

Job Position	Number of Respondents
Managing Director	18
Sales Director / Manager	11
Marketing Director / Manager	3
Export Director / Manager	3
Quality Manager	2
Purchasing / Finance Manager	2
Sales and Marketing Director / Manager	2
General Manager	2
Others	5
Total	**48**

Table 53: Job Position of Respondents

8.4.2 Product Categories – Co-Occurring Activities

The author initially assumed that independent remanufacturers would generally remanufacture more than one product group. This assumption was made on the basis of several premises. First of all, it was expected that profitability is the main driving force of an independent remanufacturing company. A widespread remanufacturing programme would have provided more options to generate profits and would have limited risks. Moreover, it was assumed that smaller and independent remanufacturing companies would have less capital to invest in machinery. Less automation, however, provides the flexibility for an extensive range of remanufactured products.

By using cross-tabulation, this section analyses Question Six and seeks to prove or disprove the initial assumptions. It will furthermore show which types of activities were more likely to be combined with each other. For example, if engine remanufacturing tended to co-occur with the remanufacturing of products from the air and fuel system.

In course of the analysis, a further product group had to be established which had not been specified while the survey was conducted. The author felt this was necessary due to the fact that there was a strong representation of power and hydraulic steering pump remanufacturers, as well as remanufacturers of flexible shafts. Hence, the product group 'chassis dynamics' was created.[63] Figure 28 shows the activities (product groups) which were performed among the responding companies. Multiple answers were possible.

[63] This product group includes all products which assist in keeping cars on the road and which stabilise the vehicle to drive into the right direction (e.g. power steering racks).

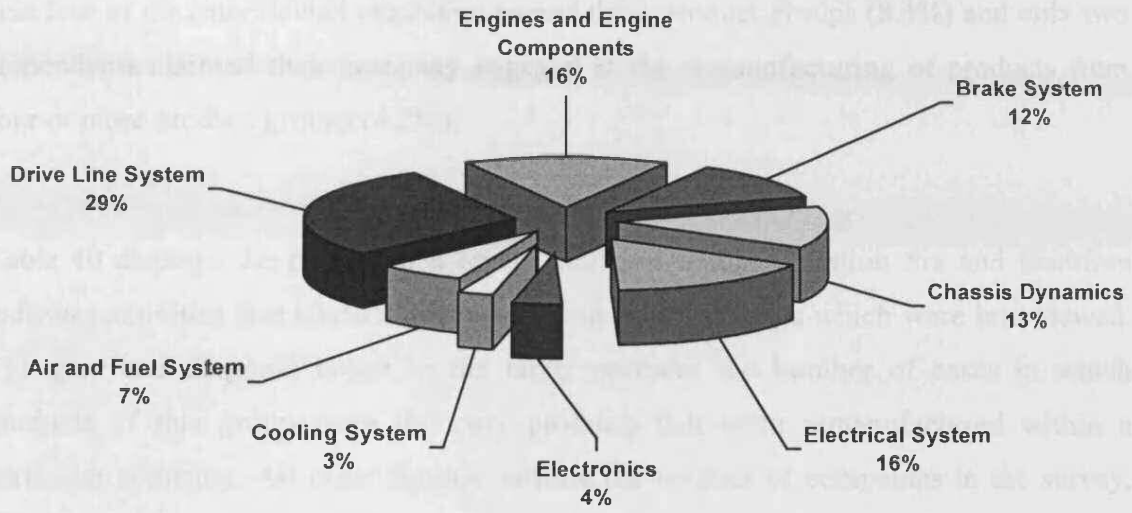


Figure 28: Shares of Product Groups among Responding Companies

Among responding companies, there was strong involvement in drive line remanufacturing, such as the recovery of transmissions and axles (22 respondents). Only three businesses that were surveyed on the trade fair carried out electronics remanufacturing. The initial assumption that electronics remanufacturing represents a very new and upcoming business sector could be confirmed (see also Walker, 2003; Weiland, 2003).

Most of the remanufacturers focused on the recovery of one single product group (30 respondents; 62.5%), which disproved the initial assumption that independent remanufacturers would generally remanufacture parts and components from more than one product group. As an interpretation of this result, one could assume that the focus on one product sector seems risky for an outsider. This is particularly true if the product group evolves from a 'star' to a 'mature' product group with high sales potential but low profitability as outlined by Weiland (2003). However, as already explained in Chapters Two and Five, many independent remanufacturers engage in further business activities, such as dynamometer testing or repair activities (e.g. Autocraft Industries UK, 2003) and may therefore decrease the risk of a focus on the remanufacturing operation.

Further twelve respondents identified two product groups of remanufacturing (25%). Just four of the interviewed exhibitors named three product groups (8.3%) and only two respondents claimed their company engaged in the remanufacturing of products from four or more product groups (4.2%).

Table 40 displays the results of a cross-tabulation within Question Six and therefore indicates activities that tended co-occur among the companies which were interviewed. The grey and diagonal boxes in the table represent the number of cases in which products of this group were the only products that were remanufactured within a particular company. All other figures indicate the number of companies in the survey, undertaking both activities at the same time. If a company was involved in three types of product remanufacturing, such as the recovery of products from the cooling system, the drive line system and the brake system, three different cases were counted for that occurrence. Case one counted the relationship between the cooling system and the drive line system, case two, cooling system co-occurring with the brake system and case three, drive line system co-occurring with the brake system.

	Electrical System	Electronics	Cooling System	Air and Fuel System	Drive Line System	Engines/ Engine Components	Brake System	Chassis Dynamics
Electrical System	5	1	1	3	3	-	4	2
Electronics		1	-	-	1	-	1	-
Cooling System			1	1	1	-	1	-
Air and Fuel System				-	2	2	2	1
Drive Line System					10	3	4	5
Engines and Engine Components						7	-	1
Brake System							2	1
Chassis Dynamics								4

Table 54: Co-Occurring Operations within Responding Companies

Table 40 shows that among remanufacturers, drive line system remanufacturing was mostly undertaken on its own. Ten companies stated that they focused on this remanufacturing activity. On the other hand, five companies remanufactured products from the drive line system and chassis dynamics in the same facilities. One interpretation of this co-occurrence of activities may have been a similar composition or technicality of products within the product groups chassis dynamics, brake system and drive line system. A further explanation could be similarities within the remanufacturing operations. A similar observation was made for the product group electrical system, which often co-occurred with brake system remanufacturing. Remanufacturing of air and fuel system parts was, in all cases, carried out alongside the remanufacturing of other parts, such as parts from the electrical system (three respondents), the drive line system, engine or brake system (each two respondents). However, engine remanufacturing seemed to be an operation which tended to be undertaken on its own (seven of thirteen cases).

8.4.3 Factors Creating Growth in the Remanufacturing Market

Question Seven aimed to identify factors which affect the remanufacturing industry positively. Interviewees were asked to indicate and rate a maximum of three aspects which they believed have a significant positive impact on their company's businesses. Overall, an 'increase in demand' had been the factor confirmed most frequently, either as 'most important', 'second most important' or 'third most important' aspect, although respondents did not always indicate three factors. Moreover, there was a difference between what respondents perceived as the main creator of growth (e.g. increase in customer demand) and the actual cause which may have led to this increase in demand. However, it could not be expected that all respondents would know the 'true' cause for the increase in demand. In cases, where interviewees chose option four ('other, please state'), they were asked to rank this aspect, too. An overview of further reasons ('other' in Table 55) are listed at the end of this section. Pressure from society, extended producer responsibility and an increase in waste disposal costs were only noted four

times and therefore seemed to be not significant among the respondents.[64] Two respondents did not indicate any factors ('no answer provided').

Factor	'Most Important'	'Second Most Important'	'Third Most Important'	Total	%
Increase in demand	16	5	0	**21**	**23.86**
Other	10	7	1	**18**	**20.45**
Easier availability of cores	7	3	3	**13**	**14.77**
Legislation	7	4	1	**12**	**13.64**
Environmentally conscious customers	3	3	4	**10**	**11.36**
Pressure from society	1	2	1	**4**	**4.55**
Extended producer responsibility	1	3	0	**4**	**4.55**
Increase in waste disposal costs	0	3	1	**4**	**4.55**
No answer provided	0	0	0	**2**	**2.27**
Total				**88**	**100**

Table 55: Factors Which Create Growth in the Remanufacturing Market (number of times confirmed)

A total of ten respondents noted further factors, which they perceived as most important for growth creation. In fact, one significant theme that emerged from additional factors added by respondents was the link between the general economic conditions and the demand for remanufactured products. Several respondents explained that due to the overall economic downturn, the demand for remanufactured automotive parts and components had increased. This disproves the statements given by Hauser and Lund (2003), who claim that according to their survey from 2003, remanufacturing companies have reported an annual increase in revenues, "even during the poor economy that has prevailed in recent years" (Schwarck, 2003a, p.14). The data obtained from this survey indicates, on the other hand, that remanufacturing benefits from recessions. One interviewee argued that "the recession or the bad economy is a major creator for growth,

[64] For a more detailed data analysis on 'most important' growth creators per product group, please refer to Appendix P.

because people don't have enough money for new products". Another respondent explained that the conversion to the Euro currency has had an impact: "With the conversion to the Euro, all products have become more expensive and people needed to save money. As a result, the demand for our products has increased". Consequently, Lund and Hauser's statement should be altered: remanufacturing has not prevailed even during the poor economy, but possibly because of it. However, this statement is not valid for very severe economic downturns, such as the recession and the fuel embargo during 1979-1980, in which car users were driving less and second and third cars were taken off the road, as Holzwasser explained in Waters (1984).

Further factors of growth noted by respondents included:

- "Poor initial design of OEM products results in a huge aftermarket demand for those parts; this demand comes with a time-lag"
- "Incompetence of car owners, who don't look after their cars"
- "Increase in car sales"
- "More and more electronics in cars" (stated by a respondent, whose company was involved in the remanufacturing of electronic components)
- "If there is the lack of a specific product in the market, we find the gap and fill it" (two respondents)
- "More marketing and information for customers"
- "(Improving) communication with market players, such as customers and distributors"
- "Producing good quality products and providing the right service"

8.4.4 Factors Restricting Growth in the Remanufacturing Market

The purpose of Question Eight was to identify the opposite factors of Question Seven. Respondents were asked to identify and rate factors, which restricted growth in the automotive remanufacturing sector. Respondents did not necessarily have to identify three factors, several interviewees only stated one or two, other respondents expressed further factors which had not been among the options of the questionnaire and one respondent did not indicate any factors.

Factor	'Most Important'	'Second Most Important'	'Third Most Important'	Total	%
No availability of cores	19	6	1	**26**	**25.24**
Competition from other spare parts	6	7	6	**19**	**18.45**
Longevity of OEM parts	4	6	4	**14**	**13.60**
OEM specifications/metrics/design	5	4	1	**10**	**9.71**
Other	5	5	0	**10**	**9.71**
Legislation	6	0	0	**6**	**5.80**
Finding markets for remanufactured products	1	4	1	**6**	**5.80**
Lack of demand	0	2	3	**5**	**4.90**
Design for disposal	0	1	1	**2**	**1.94**
Product proliferation/diversity	1	0	1	**2**	**1.94**
Achieving economies of scale	0	0	2	**2**	**1.94**
No answer provided	0	0	0	**1**	**0.97**
Total				**103**	**100**

Table 56: Factors Rated as Important Growth Restrictors by Respondents

Table 42 shows that 'no availability of cores' has been seen as the most significant restrictor of growth, with 26 respondents rating it as important, whereof 19 claimed this aspect was the 'most important' restrictor of growth.[65] Moreover, the questionnaire results verified the observations of the case study research, in which the OEM remanufacturer had explained that one of the main strategies was a thorough and nearly aggressive collection of cores in order to eliminate the independents' access to cores.

Competition from other spare parts, such as new or repaired replacements, as well as the longevity of the original equipment were two further factors which respondents rated as important. Very surprisingly, the lack of demand had not been perceived as a major

[65] For a more detailed cross-tabulation of 'most important' factors restricting growth (per product group), please refer to Appendix Q.

restrictor of growth, despite the "increase in demand" being rated as the definite creator of growth in Question Seven.

Further factors mentioned by respondents included:

- "More electronics in cars"
- "Different vehicle manufacturers have different product designs. Hence, investment in all the different machinery to handle this diversity slows down growth"
- "OEM does not provide very small new parts, which are needed in the remanufacturing process. These have to be handmade and are very therefore very expensive"
- "Fierce competition from OEM"
- "Ex-leased cars drop into the market with the result that demand for remanufactured engines decreases"
- "Price competition with independents; quality and image suffer"
- "Minor quality products from other remanufacturers has negative impact on the whole sector"
- "Competition from 'cut-outs'[66]

8.4.5 Market Demand and Profitability

Overall, the largest group of respondents claimed that the market demand for the product areas in which the company operated was growing slightly (21 respondents or 43.75%). Thirteen respondents said it was stable (27.1%). Only eight respondents stated that the demand for their products had increased significantly and just two interviewees confirmed that the demand for their products was decreasing significantly. However, 29 of 48 respondents claimed there was slight or significant growth and just six respondents had perceived decreasing market demand. Hence, it may be concluded that the remanufacturing sector was prospering at the time of research (June 2003).

[66] 'Cut-out' parts are parts retrieved from vehicles that were involved in accidents (cannibalisation).

This section seeks to investigate the correlation between the product groups and market demand. This information may reveal the different remanufacturing life cycles for the product groups. Table 57 displays the market assessment given by respondents. The responses of companies engaging in the remanufacturing of parts and components from various product groups, has resulted in multiple counting (i.e. one count for each of the product groups, but each time for the same market assessment). The table shows that the product groups electrical system, electronics, cooling system and air and fuel system seemed to experience either slight or significant increases in demand. No respondent felt that there was a decrease in demand for these product groups (Table 57).

Product Group	Growing Significantly	Growing Slightly	Stable	Declining Slightly	Declining Significantly
Electrical System	4	4	4	-	-
Electronics	1	2	-	-	-
Cooling System	-	2	-	-	-
Air and Fuel System	1	4	-	-	-
Drive Line System	3	9	5	3	1
Engines and Engine Components	-	5	4	1	1
Brake System	3	4	2	-	-
Chassis Dynamics	2	5	2	1	-
Total	**14**	**35**	**17**	**5**	**2**

Table 57: Market Demand Assessment by Product Group

Despite the majority of respondents claiming that demand for their remanufactured products had increased, the absolute majority of respondents expressed that profitability had decreased since the year 2000 (18 respondents). A further fifteen respondents claimed it has remained stable and nine said they felt that profitability had increased (two respondents did not indicate any option). Table 58 shows the change in profitability (since the year 2000) per product group.

Product Group	Increased	Remained Stable	Decreased	'Don't Know'
Electrical System	1	2	6	3
Electronics	-	2	1	-
Cooling System	-	1	1	-
Air and Fuel System	1	2	1	1
Drive Line System	2	6	11	3
Engines and Engine Components	3	4	4	1
Brake System	-	3	5	1
Chassis Dynamics	3	3	-	1
Total	**10**	**23**	**29**	**10**

Table 58: Perceived Change in Profitability since the Year 2000 by Product Group

In Question Eleven, respondents were asked why they felt that profitability had changed in the way they indicated. A large number of respondents who stated that overall profitability had decreased since the year 2000 expressed that increasing competition was the cause for the decrease in profitability. In fact, individual orders seemed to have generated smaller profit margins than in the years before 2000. One interviewee noted that there has been competition from new Chinese parts, another respondent claimed there have been manufacturers from Asia, Italy and Spain copying new OEM products. "You have to be more aggressive in the market, nowadays. The customer is more demanding, because it's easy to compare prices on the internet", one respondent stated. Moreover, respondents observed that competition among remanufacturers had increased, too.[67]

It was also confirmed that more and more OEMs have entered the remanufacturing market. One interviewee explained that "there is a shift in the industry from independent remanufacturing towards remanufacturing undertaken by OEMs. OEMs are becoming more and more involved and they possess all the equipment, which is a major competitive advantage. Our profit margins used to decrease with other products. Now we only focus on products that really make profit".

[67] Western European remanufacturers experienced competition from low-wage Eastern countries, such as Poland. This was confirmed by a Polish remanufacturer who observed that profitability decreased in the Polish market, but increased for foreign markets.

In addition, due to increasing warranties on new cars and car parts as well as decreasing prices for second-hand cars, the 'aftermarket-window', in which remanufactured products could potentially be sold, has decreased. "There used to be a sales opportunity from year one to year ten of a car's age. Now, that VMs give between three and five years of warranty, our potential marketplace has decreased", one respondent remarked.

8.4.6 Foundation of the Business

In Question Ten, respondents were asked to express their company's main reason for being involved in the remanufacturing business. Although the question asked for the main reason, the author left room for the respondents to express further motives. The data analysis included the grouping of the answers into main categories. These categories covered the business point of view (profit making; extension of an existing business), a market-related standpoint (filling a gap in the market), as well as personal reasons (family-business; 'turn a hobby into a business'). In many cases, these factors had been interrelated. For example, one respondent explained that his distinctive expertise and accumulated knowledge on certain automotive products had developed into a business opportunity. Another respondent outlined that he inherited his father's business, which had been initially created on the basis of a hobby. Hence, in these cases, two counts were registered. The following Table 59 displays the results.

Perspective	Main reason(s) to being involved in this business sector	Number of Respondents
Business	'Making Profit'	13
	'Expansion of Existing Business'	8
Personal Disposition	'Family'	11
	'Hobby or Expertise'	8
Market	'Business Opportunity'	10
	'Other'	1

Table 59: Main Reason for Involvement in the Automotive Remanufacturing Sector

The category 'making profit' included the profit as main driving force. It is therefore different from the category 'business opportunity', since in the latter category, respondents perceived the main focus to be the lack of a certain product in the market,

for which there was a demand. The business opportunity is therefore rather seen as market-driven motive where responding companies identified a gap in product choice, which they intended to fill. However, these two motives were strongly linked. The category 'extension of existing business' included six cases in which the responding company claimed to have developed from 'distributor' to 'distributor *and* remanufacturer'. In most cases, this business extension was a result of decreasing profit margins or decreasing demand in the distributing part of the business so that the incorporation of the remanufacturing operation aimed to stabilise the whole business.

The rubric 'personal disposition' included two sets of respondents. Several respondents argued that they had either inherited the business or they had established a remanufacturing business with a relative. These respondents fell into the category 'family'. The second part of the group 'personal disposition' comprised eight interviewees who explained they had either turned a hobby into a business or their expertise or interest in this business sector has led to the establishment of a remanufacturing company. Table 59 has shown a nearly equal number of respondents for business-related motives than for personal disposition.

8.4.7 Merits and Considerations

There were several points which had to be considered within the interpretation of the results. One of the questionnaire's drawbacks was the impossibility of piloting the questionnaire within the population. In addition, no market study was available to confirm that the sample was representative.

The questionnaire survey was conducted in English. However, given the different origins of respondents, the language barrier may have distorted results due to misunderstandings or translations of questions. Moreover, as pointed out in Chapter Four, survey results may be biased in a way that respondents gave answers which they perceived as politically or ethically correct rather than responding 'truly'.

The survey's merits include the self-administration of the questionnaires by the author. As previously pointed out, this has eliminated response bias. Random sampling was replaced by 'self-selection', which included the exhibitors as a sample of the whole

population. As previously noted, the validity of the research findings was increased by the characteristics of companies exhibiting on the trade fair. These were assumed to be companies with strong industrial involvement and good business practice.

8.5 Conclusion

The questionnaire survey had several purposes. It aimed at testing, validating and generalising the results from the preceding case study research. Hence, observations from the case study research, such as the motives for remanufacturing were tested with regard to their validity for different product groups and market players. Other case study findings, such as the competition for cores, could be confirmed by the survey.

This questionnaire survey has provided insights into the European remanufacturing sector, with a strong emphasis on independent remanufacturing. It has been one of the first attempts to collect descriptive data on the European automotive remanufacturing sector, with previous research investigating the North American remanufacturing industry. The questionnaire survey was undertaken alongside in-depth case study research on original equipment remanufacturing. The data was not collected in isolation, but collectively with in-depth industry insights from interviews, seminars and workshops organised by the two main remanufacturing associations.

The questionnaire results were strongly influenced by a Western European perspective (92% of respondents) and by the respondents of three countries: the United Kingdom (28% of the respondents), Germany (25% of the respondents), and The Netherlands (23% of the respondents). Moreover, the product groups driveline system, engine components and electrical products were predominant among responding companies. Most of the responding companies were independent remanufacturers with less than 250 employees being involved in the remanufacturing activities. The interpretation and conclusions drawn from the results will be presented in Chapters Nine and Ten.

Chapter Nine
Attributes of Automotive Closed-Loop Supply Chain Structures

9.1 Introduction

Chapter Two has discussed generic closed-loop supply chain and remanufacturing structures. These structures were criticised with regard to their lack of applicability to automotive remanufacturing. Moreover, they were found to be too generic. As a result, two research questions which referred to the creation of automotive closed-loop supply chain and remanufacturing structures had been developed. Research Question 1 asked which closed-loop supply chain structures are relevant to the automotive industry. The second research question aimed at the identification of remanufacturing process structures that are relevant to the automotive sector.

Chapter Nine, however, takes a step back by commencing with a discussion of the terminology within closed-loop supply chain management. Existing definitions and ideas have often been vague and not perceived as entirely suitable for the automotive sector. As a result, the first part in this chapter develops key definitions and conceptual models for automotive closed-loop supply chain management on which the automotive closed-loop supply chain and remanufacturing structures can be based. The result is the

suggestion for a new terminological framework for closed-loop supply chain management. Thereafter, the two product groups of this dissertation, engines and electronic devices, are taken as examples to demonstrate the applicability of the newly developed framework. With regard to Research Question 1, two automotive closed-loop supply chain structures for OEM remanufacturing are developed.

The second part of this chapter links the two research questions and the theoretical discussion on the major uncertainties and obstacles within remanufacturing (Chapter Two) with what has been observed in this research. As a result, new insights and detailed process data on 'real-world' OEM remanufacturing issues may provide specific starting-point and assumptions for future research.

Overall, this chapter demonstrates that it may not be assumed that conceptual closed-loop supply chain and remanufacturing process structures are applicable to any product within any industry and any case. Instead, closed-loop supply chain models and (in-plant) remanufacturing models need to be adapted to the specific research environment. This particular framework is suggested for the specific cases and circumstances that have been investigated within this research, including a specific emphasis on the automotive sector, the Original Equipment Manufacturer and the two product groups.

9.2 Closed-Loop Supply Chain Structures for the Automotive Sector

This section seeks to establish an understanding of the closed-loop for the automotive sector. It does not consider simple reverse logistics processes, such as commercial returns, but refers to closed-loop supply chains in which a full recovery process (as defined in Chapter Two) takes place. Hence, examples of the re-use of toner cartridges or single use cameras (e.g. Guide and Van Wassenhove, 2002b, 2003a) as well as commercial returns (e.g. Blackburn *et al.*, 2004; Tibben-Lembke, 2004), are excluded from the following discussion.

This section discusses the complicating factors of closing the automotive loop. It is generally perceived that the term closed-loop supply chain has often been applied loosely and no detailed account is given with regard to the criteria that define a supply chain or a loop as closed. Moreover, there are a large number of diverse understandings

with regard to the closed-loop in general and the extent to which a loop may be closed. This section therefore aims to develop key definitions and models for automotive remanufacturing. The need for this clarification has been raised by Research Questions 1 and 2 (Chapter Two) and has been developed throughout the research (e.g. Chapters Six and Seven). Hence, the key terminology and models are based on the findings of this research, but also on the experience and knowledge the author has accumulated throughout the whole research process.

9.2.1 Defining the Automotive Closed- Loop Supply Chain

This section refers to Research Question 1, which was phrased as: Which existing closed-loop supply chain structures are relevant to the automotive industry?

After the review of existing closed-loop supply chain structures in Chapter Two and the examination of real-world cases (Chapters Six and Seven), this section firstly develops a conceptual framework for closed-loop supply chain management, which is afterwards applied to the automotive sector.

Two of the main contributors in the area, Guide and Van Wassenhove (2003a) have identified the closed-loop supply chain as a supply chain in which reverse logistics and product recovery take place. However, there is a need for further distinctions. This research has found that the remanufacturing of engines and electronic devices does not lead to a genuinely, fully closed-loop. While some contributors argue that a closed-loop system requires that there are "[...] no virgin materials added and everything is recycled and re-used" (Wells and Nieuwenhuis, 2001, p.37), it is still questionable if such a closed-loop system can be achieved in cases where products have left the factory gates. An in-plant closed-loop system may therefore be termed 'simple closed-loop', since waste material within the production process may be fed back.

As a result, the 'extended closed-loop' is characterised by customer involvement. It is furthermore assumed that any recovery activity within the extended closed-loop (recycling, remanufacturing, re-use) incorporates system loss. Concluding, there are two key distinctions between a simple and an extended closed-loop. As a general rule, it may be stated that within the simple closure of the loop, the material does not necessarily

undergo a degradation but may be of the same quality than virgin material. The extended closed-loop, on the other hand, usually reflects a degradation of materials, such as the use of materials in the production of other products or the distribution of recovered products on non-premium (secondary) markets. An essential dimension of the understanding of both concepts is the fact that a 'loop' is only achieved if material and parts are transformed into the same product.

As the term closed-loop supply chain suggests, the emphasis is put on a closed system. Chapter Three has outlined that the idea of an endless, repetitive materials or product cycle has been borrowed from industrial ecology theory, but the definitions for open and closed systems can be taken from systems theory. There are different understandings of open and closed systems. Ogata (1998) is referring to closed systems (or feedback control systems) as systems in which there is a relationship between output and (reference) input. Such feedback control systems compare the difference between input and output and use this difference as a means of control. In open-loop control systems the output has no effect on the control action (Ogata, 1998).

Within this dissertation, however, a product flow perspective was taken. A more appropriate definition is therefore given by Fleischmann *et al.* (1997), who describe open-loop systems as those in which products do not return to the original producer. According to Fleischmann *et al.* (1997), recycling often leads to an open-loop system. As the discussion in Section 2.4.2 has indicated, it may be assumed that remanufacturing may lead to closed-loop systems. By applying this perspective on this research, closed systems indicate that materials or parts are transformed into the same product within the recovery process. Hence, open systems are characterised by materials and parts 'leaving' the loop. This may occur by their incorporation into secondary products, which often involves material degradation. A good case in point is the use of recyclates in the production of non-premium products. However, this section does not consider open systems, although some contributors may claim that these may represent waste-free processes which should be a part of the discussion.

The second distinction between the 'simple loop' and 'extended loop' concept refers to the amount of material or product parts that can be fed back into the system. In a simple

closed-loop there may be cases in which the waste material can be fully used in the production of the same product. The percentage of re-usability decreases with every step further down the production process. A good case in point is the production of a car parcel shelf. Waste material may be easily fed back into the thermoplastics production process. However, as soon as the plastics have been covered with a second material, separation may become impossible. Within the extended loop, system loss (i.e. scrap) is, in most cases, part of the process. Concluding, it may therefore be claimed, that the 'simple closed-loop' may represent a waste-free process, whereas the 'extended closed-loop' tends to incorporate waste. As a result, there are 'fully closed' and 'nearly closed' loops. A fully closed-loop indicates that the process is free of waste. A nearly closed-loop, on the other hand, involves waste. Table 60 summarises the key terminology which has been developed within this section.

Term	Characteristic
Simple loop	In-plant material feedback process
Extended loop	Customer or end-user involvement
Fully closed	Waste-free process
Nearly closed	Process involves waste
Closed system	Incorporation of materials and parts into the production of the same product
Open System	Production of secondary product; often incorporates material degradation
Genuine closure	Production output is distributed as 'new' product on a premium market
Modified closure	Production output is not classified as 'new' and distributed on a secondary, non-premium market

Table 60: Delineation of Closed-Loop Terminology

Figure 29 illustrates the understanding of a simple loop. A simple loop is achieved if the material is fed back into the production, as material flows number 1 and 2 in the graph demonstrate. The loop may be fully closed if no waste occurs. Flows number 3 and 4, on the other hand, demonstrate open systems. The waste of one production process either serves as a (raw) material within the production of a second, different product (flow number 3) or is diverted to another production plant, in which the material serves as (raw) material to the process (flow number 4).

It may be assumed that the flows indicated by figures 3 and 4 involve material degradation and therefore cannot follow the routes indicated by material flows 1 and 2. Moreover, this discussion takes a very strong focus on materials. It is assumed that parts and components are less likely to achieve the fully, simple closed-loop. With regard to parts and components, one form of the simple closed-loop may be achieved if parts undergo a repair process after failing the quality inspection. However, this case does not fully comply with the definitions in Table 60, since those parts do not represent waste as such.

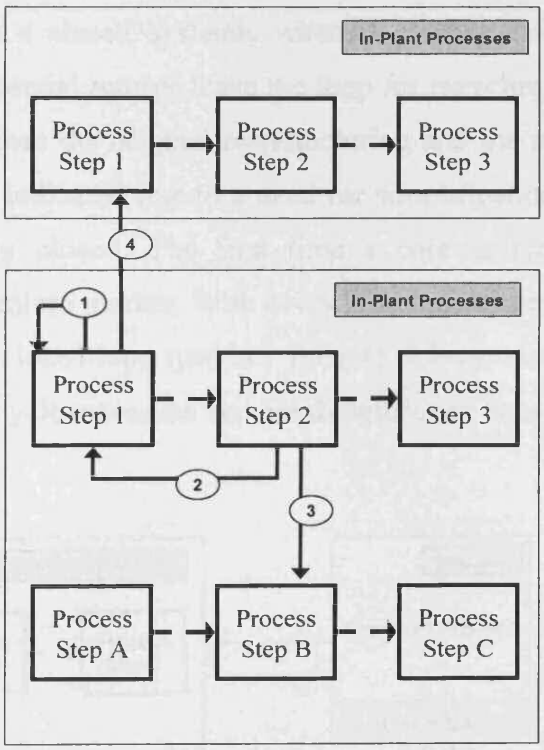


Figure 29: Simplified Model of 'Simple Loops' in Open and Closed Systems with a Material Focus

The extended closed-loop, on the other hand, involves the customer or the end-user, as Figure 30 shows. Product flow 1, which may be perceived as the ultimate objective of industrial ecology and closed-loop supply chain management (as outlined in Sections 2.4 and 3.2), shows a genuinely closed-loop. For reasons of simplification, the recovery process which precedes the integration of the material or parts into process step 1 has been omitted. However, product flow 1 is assumed to incorporate system loss (waste), since parts or materials are returned to a standard in which they may be incorporated

into the production of a new product. Moreover, product flow 1 assumes the production of an identical product (closed system). There are few empirical examples for this type of product flow, such as the remanufacturing of photocopying machines or printers (e.g. Maslennikova and Foley, 2000). In most cases, remanufacturing leads to products being classified as 'remanufactured' and distributed on a secondary market (e.g. Guide and Van Wassenhove, 2003a), which is indicated by product flow 2 in Figure 30. Product flow 2 is typical for automotive remanufacturing, as the research findings have demonstrated. Remanufactured product may be distributed on the same market than 'new' products (e.g. aftermarket), or on an alternative market (e.g. 'grey' market). Product flow 1 shows a closed systems, whereas product flow 3 indicates an open system. Product and material returns leave the loop for recycling. This third stream may also consist of waste from the original manufacturing and the recovery plant, but these streams have not been indicated due to a need for simplification. Product flow 2 could be classified as nearly closed. The first time a core is remanufactured, the core originates from the premium market. With every remanufacturing process thereafter, the product can achieve a closed-loop (product flow 4). Re-use and repair operations only result in a product life cycle extension and are therefore not considered at this point.

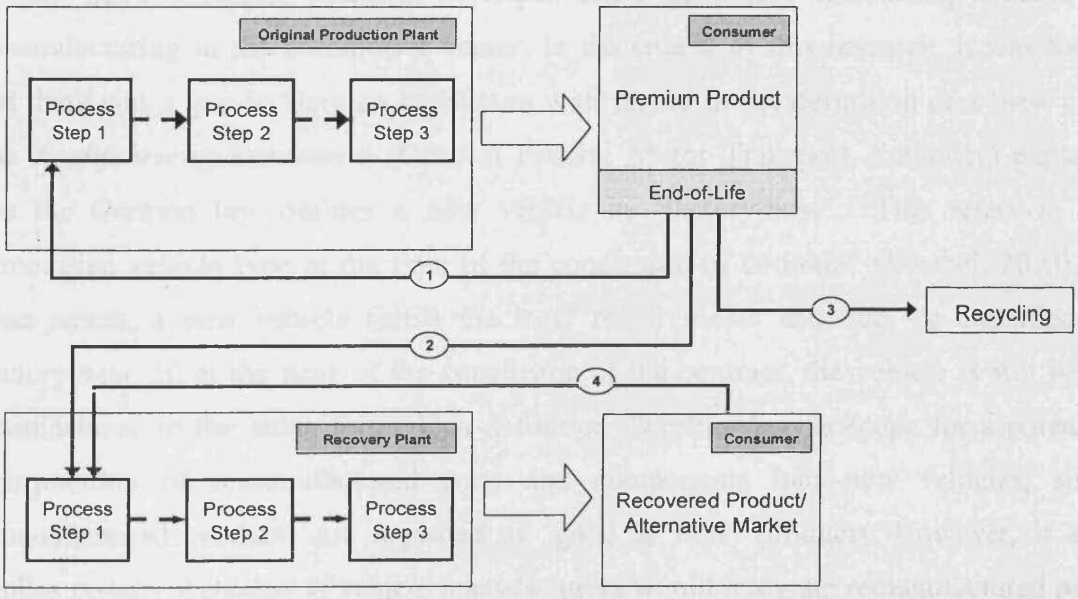


Figure 30: 'Extended Loop' in Closed and Open Systems with a Focus on Remanufacturing

With regard to the automotive sector, Chapters Two and Three have demonstrated the issues within the closure of the automotive loop. As a matter of fact, in-plant recycling may occur (simple loop). However, extended closed-loop recycling processes, such as car recycling, incorporate difficulties. Most of current industry practice which involves the consumer or end-user leads to open systems including material degradation. The producers of high-end luxury cars, such as Case Company A, carefully chose the materials that are incorporated into their cars. In some cases, they may be rather reluctant to use recycled materials, since the plastic moulding process is more reliable, if virgin materials are used. This is different for remanufacturing. However, it is still questionable whether the automotive industry seeks to achieve a closed-loop economy. Deutz (no date given), confirms:

> *Because many lower tier suppliers within the automotive sector supply components exclusively for automotive manufacture, this can present obstacles to the re-use of downgraded materials. These need to be pushed into other uses where materials criteria are less critical in respect of safety and other attributes.*
>
> (Deutz, no date given, p.14)

In fact, there is (legal) potential to implement a genuinely closed-loop system for remanufacturing in the automotive sector. In the course of this research, it was found that there was a gap in German legislation with regard to the definition of a 'new car'. The *Kraftfahrzeug-Bundesamt* (German Federal Motor Transport Authority) explains that the German law defines a new vehicle as 'factory-new'. "This refers to the unmodified vehicle type at the time of the conclusion of contract" (Wrobel, 2003). In other words, a new vehicle fulfils the legal requirements and may be classified as 'factory-new' if, at the time of the conclusion of the contract, the vehicle is still being manufactured in the same form. This definition therefore leaves scope for a potential incorporation of remanufactured parts and components into new vehicles, since remanufactured products are regarded as 'good as new' products. However, it also implies certain obstacles. If vehicle manufacturers would integrate remanufactured parts into new vehicles, every vehicle would need to meet the same norm with regard to amount and quality of remanufactured content. A second obstacle, which has been demonstrated by this research are the various uncertainties incorporated within product

recovery, such as automotive remanufacturing. In the automotive industry, manufacturing and assembly processes are highly structured and incorporate just-in-time deliveries. The use of remanufactured products in the vehicle assembly process, for example, would suffer from the uncertainty incorporated in remanufacturing. In addition, the automotive industry is characterised by the production of safety-sensitive goods. The closure of the total materials cycle may even collide with product liability concerns, caused by a potential material degradation during recycling or remanufacturing. It is therefore questionable to which extent vehicle manufacturers would risk product liability charges with regard to remanufactured products in new vehicles. An increasing amount of 'used' parts in vehicles could also affect the brand image.

Consequently, this indicates that there is scope for achieving the 'genuinely', extended closed-loop in the automotive sector, as it has been shown by product flow 1 in Figure 30. However, from an empirical perspective, the above discussion has demonstrated that this is rather unlikely to become standard practice in the automotive sector. It is therefore concluded that product remanufacturing in the automotive sector does not represent a fully, but a nearly closed-loop since waste occurs (product flows 2 and 4 in Figure 30). It is also characterised as extended loop, since the customer is involved in the process. Due to the fact that remanufactured automotive parts are 'downgraded' to a different marketplace, parts remanufacturing represents a modified closure of the closed-loop chain. In fact, since an engine, for example, may be remanufactured several times, a repeatable loop may be achieved in this alternative market. As a result, automotive remanufacturing may be classified as the nearest state to a genuinely closed-loop that may be achieved within the automotive sector. However, complete genuinely closed-loops are outside current automotive industry practice.

9.2.2 Identification and Analysis of Automotive Closed-Loop Structures

Chapter Two has outlined that existing research has developed generic closed-loop supply chain models in which products and materials from recovery streams (recycling, re-use, repair and remanufacturing) re-enter the 'forward' supply chain at specifically

indicated points (see, for example, Thierry *et al.*, 1995; Krikke *et al.*, 2004). As a result of this research, such models have now been termed the extended, genuinely closed-loop. These models may be applicable to certain industry sectors. However, they cannot be fully applied to the automotive sector. The reasons for the limited applicability have been outlined in the previous section. It has also been demonstrated, that the automotive industry currently shows a different practice than the product flows indicated in the conceptual closed-loop models. This dissertation has shown that there may be a condensation of distribution and collection channels, such as the use of forward distribution channels for core collection, however, this is not identical to what previous research has indicated in the closed-loop supply chain structures (e.g. Thierry *et al.*, 1995; Guide *et al.*, 1999; Majumder and Groenevelt, 2001b; Meade and Sarkis, 2002; Mahadevan *et al.*, 2003; Krikke *et al.*, 2004). As a result, there is the need for the display of detailed, industry-specific closed-loop supply chains.

This section therefore refers to Research Question 1 which has been identified in Chapter Two: Which existing closed-loop supply chain structures are relevant to the automotive industry? Following the discussion within the previous section, the engine closed-loop supply chain has been developed with regard to this research. The closed-loop supply chain models which have been presented by Guide and Van Wassenhove (2003a) for a variety of industries, have hereby been taken as a blueprint for the illustrations.

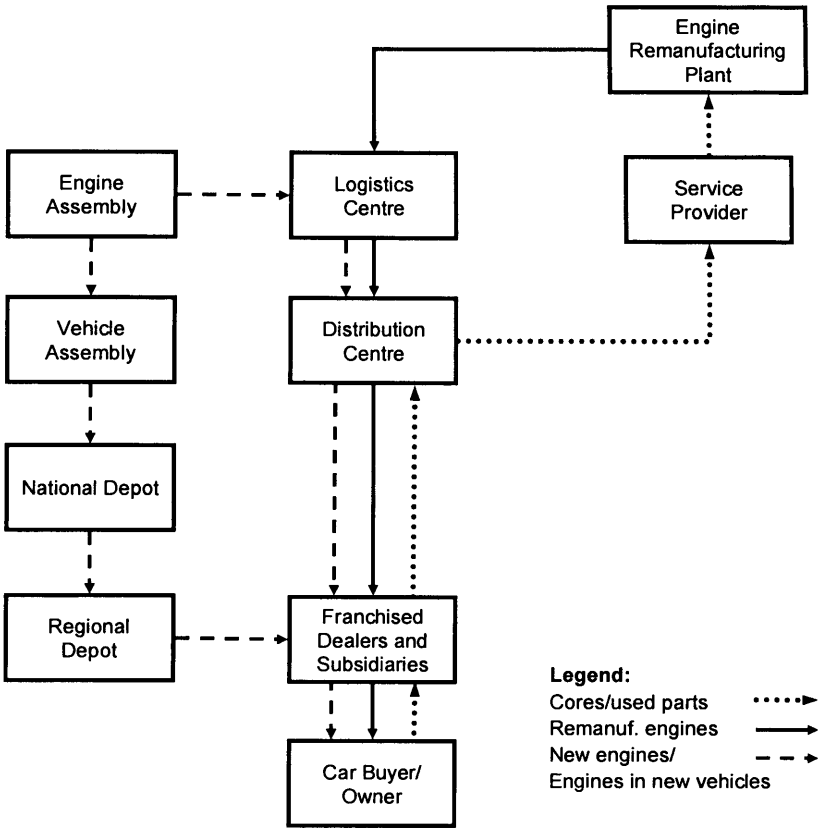


Figure 31: Closed-Loop Supply Chain for Engines: OEM Perspective

Figure 31 displays the model of Company A's closed-loop supply chain for car engines. Order, product and financial flows have been described in Chapter Six. The above graph shows that engine remanufacturing represents an extended, modified closure of the loop. As a result, there are two different, but interlinked supply chains. Their point of contact is the shared distribution and collection network, respectively. New engines are distributed within new vehicles, but may also be sold individually as spare aggregates. Remanufactured engines return via a regional distribution centre and are recovered in a separate plant. Several findings can be identified from this research and the above closed-loop supply chain structure.

Firstly, this research has found that only extended closed-loop supply chains require reverse logistics, as it has been defined in Chapter Two. Moreover, the genuinely closed-loop, in which returned and recovered materials or parts are integrated into the

production of new, premium products is most likely achieved by the original producer of the product. In the above graph, this would indicate a product flow from the engine remanufacturing plant to the vehicle assembly. In addition, this thesis has demonstrated why generic models do not seem to be applicable to the automotive sector. In some industries, such as the remanufacturing of photocopying machines or printers (e.g. Maslennikova and Foley, 2000), recovered components are fed back into the same assembly line as virgin parts. However, this research has discovered that this is not true for passenger car engine and electronic device remanufacturing. Figure 31 shows two different plants for (re)manufacturing, hence, original production or assembly lines are not used for manufacturing and remanufacturing simultaneously. These results have to be considered in the closed-loop supply chain design. Previous supply chain structures, such as by Meade and Sarkis (2002) or Majumder and Groenevelt (2001b) have not been precise about where recovery takes place. Instead, recovered products seem flow back automatically to be incorporated into new product assembly.

With regard to electronic device remanufacturing there are two cases, as Chapter Seven has demonstrated. On the one hand, there are zero-mile product returns, which represent products which have not left the vehicle assembly plant. Within the case study, electronic device manufacturing and remanufacturing may have taken place on the same premises, but not within the same (re)manufacturing lines.[68] These products therefore represent a special case of a fully closed system. Due to the fact that the devices have not been in touch with the car buyer or the retailer, this product flow cannot be described as 'extended loop'.

The second case of product returns which has been described in Chapter Seven was 'field returns'. Cores and remanufactured devices have taken routes which were similar to the product flows of engines (cores and remanufactured). There are only two distinctions. On the one hand, electronics manufacturing and remanufacturing is performed by a supplier. On the other hand, electronics manufacturing and

[68] No failure found devices (NFF) may have been re-used in the assembly of new vehicles if the products were up to date. It may be assumed that (nearly) no recovery was needed in these cases. However, since the underlying research focused on remanufacturing, these products are excluded from this discussion.

remanufacturing within Case Company D may take place within the same plant, but not within the same facilities.

In fact, equipment from an outdated production line may be of use within the remanufacturing process. However, the identical facility is never used for manufacturing and remanufacturing at the same time. In other words, the findings of this research have shown that OEM manufacturers that undertake remanufacturing activities tend not to perform those processes in hybrid manufacturing/remanufacturing plants. Within the electronics case study, interviewees had explained that Case Company D initially sought to integrate the remanufacturing processes of electronic devices into the 'repair loop' ('repair bay') of the serial production. This set-up failed, since employees on the line were not able to split their time between remanufacturing and manufacturing (repair of assembly-line failures). Moreover, there was an increasing confusion about different product generations and variants amongst employees on the line. One interviewee confirmed:

> *Within the manufacturing of new electronic devices the processes are always the same. Within electronic device remanufacturing, the process is different for each individual device. Our intention of bringing manufacturing and remanufacturing process together failed because of this distinction in the processes.*[69]

As a result, the electronics closed-loop supply chain may be described as an extended, nearly closed-loop in which remanufactured devices are not classified as 'new', but as remanufactured spare parts (modified closure). It may even be claimed that this electronics closed-loop supply chain is even closer to the definition of a genuine closure than the engine closed-loop supply chain (see Figure 32).

[69] Quoted from the interview with the Manager for IT Integration at case Company D, July 2003, translated from German.

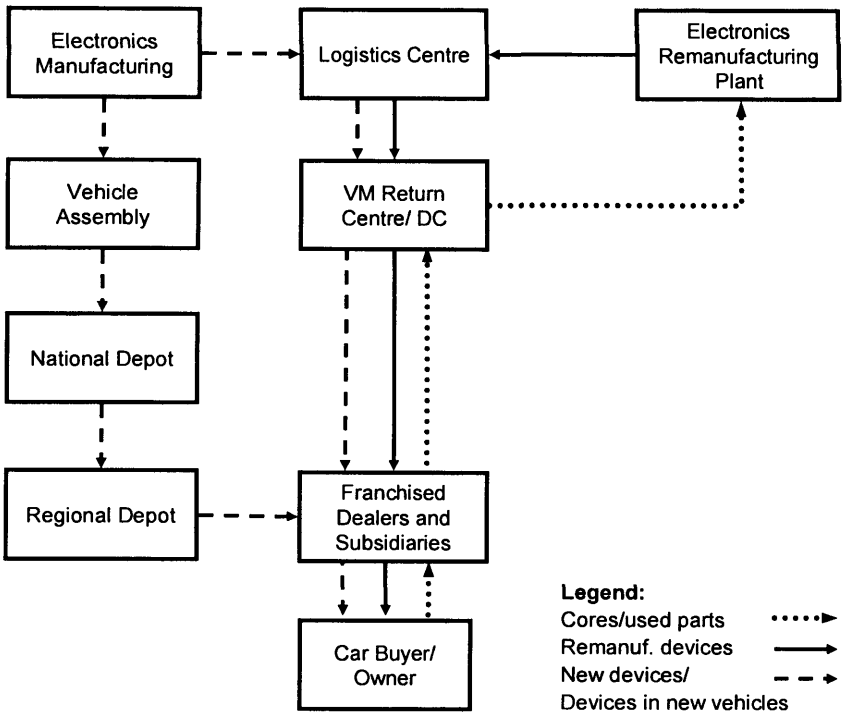


Figure 32: Company B's Closed-Loop Supply Chain with Supplier D (Electronic Devices)

There are several reasons for that. Firstly, it may be assumed that an electronic device can be upgraded to the quality level of a new product. This is even more likely for electronics than it is for mechanical components, since software updates may bring back the electronic device to this level.

Secondly, in most warranty cases, the car owner receives a remanufactured electronic device. This device has been remanufactured and 'wear' parts have been completely replaced.

Thirdly, a genuine closed-loop could be achieved by electronics remanufacturing.[70] In other words, the incorporation of a remanufactured electronic device into a new car is even more likely to take place in the case of electronic devices than in the case of a remanufactured engine. This is due to the fact that entertainment devices are not directly related to safety features of the car.

[70] In Figure 32, a genuine closure would be indicated by a product flow from the electronics remanufacturing plant to the vehicle assembly plant.

Fourthly, remanufactured electronic devices are less likely to be identified as remanufactured products than engines. Chapter Six has shown that some engine components may change their diameters during remanufacturing. Remanufactured electronic devices, on the other hand, may only be identified with their specific product number for remanufactured parts. Since an entertainment unit, for example, does not interfere with the direct safety of the vehicle, there is more scope for vehicle manufacturers to incorporate remanufactured electronics into new cars.

However, there are two drawbacks. Firstly, as previously outlined, remanufacturing incorporates high uncertainties which may interfere with current vehicle assembly practice. Secondly, remanufactured electronic devices represent a significant source of warranty replacements and therefore an essential supply of spare parts. It must be assumed that vehicle manufacturers may not be willing to relinquish this important source of spare parts.

9.3 Automotive Remanufacturing Process Structures

The review of literature (Chapter Two) has demonstrated that previous research has presented in-plant descriptions of remanufacturing processes for other industries. Contributions with regard to the automotive sector have been made by Johannes (1995) and Steinhilper (1998), who focus on a practitioner audience. Theoretical contributions with regard to inventory control were made by Van der Laan (1997) and Langella (2003) has investigates disassembly planning. As a result, this dissertation sought to fill a gap in academic research by presenting a detailed, real-world automotive engine remanufacturing process structure in Chapter Six and for electronics in Chapter Seven. These models both refer to Research Question 2: Which existing remanufacturing process structures are relevant to the automotive industry? A typical engine remanufacturing process was presented in detail in Section 6.4. The electronics remanufacturing process structure was discussed in Section 7.6.2. Both processes will not be repeatedly presented in this chapter. Instead, this section seeks to compare research outcomes that were expected on the basis of the review of literature with the actual research findings (as shown in Tables 47 and 48 in Chapter Six and Tables 49 and

50 in Chapter Seven). The section also seeks to find an explanation for the gap between expectations and outcomes. Due to the fact that OEM electronics remanufacturing has only been undertaken from the late 1990s onwards, less descriptive data was available for this product group. As a result, this section puts a strong emphasis on engine remanufacturing.

This section therefore aims to discuss the issues and obstacles surrounding the automotive remanufacturing process structures which have been developed from the research (see Section 6.4 and 7.6.2). The discussion hereby focuses on the environment of these models and specific issues which have been discovered. The aim is to provide industry specific, real-world assumptions and starting-points for further research in the area. A particular emphasis is put on the difference between the challenges that were proposed by the literature and the real-world challenges that emerged within the in-depth case study research.

9.3.1 Remanufacturing – Proposed Challenges

The literature review on supply chain management and closed-loop supply chain management in Chapter Two has presented major uncertainties within product recovery management and reverse logistics. Several categories of obstacles could be identified from the literature. These included sources of uncertainties related to reverse logistics, such as the collection structure complexity and the uncertainty concerning the quantity, quality and timing of reverse flows. From a supply chain perspective, the integration of forward and reverse flows has been perceived as a complicating factor. Taking an in-plant perspective, Guide (2000) further adds that production planning and control is more complex for a remanufacturing facility than for a traditional manufacturing facility, due to the fact there is a lack of tools and technologies to support production planning. He also claims that the necessity of product disassembly further complicates remanufacturing management. Chapter Two has furthermore outlined the tools and techniques offered by quantitative research in order to support remanufacturing activities. Given the uncertainties and complicating factors identified within previous research, the research findings are compared to the academic assumptions.

Reverse Logistics

Chapter Two has demonstrated that there is a vast body of literature on reverse logistics. However, it has often been criticised that previous work on reverse logistics research lacked in breadth. Fleischmann *et al.* (1997) have discovered that much of the previous research has been isolated and taken a narrow view on specific aspects. Knemeyer *et al.* (2002) add that previous research has neglected 'real world' reverse logistics factors which result in the complexity of these systems. In particular, reverse logistics has dealt with identifying, discussing and analysing appropriate logistics structures "[...] for bridging the gap between two market interfaces, namely acquisition of used products on the one hand, and sales of reusable products and materials on the other hand" (Fleischmann, 2003, p.119). These aspects have been described more generally as 'issues in reverse logistics network design' (e.g. Fleischmann 2001, 2003; Fleischmann *et al.* 1997; Fleischmann *et al.* 1999; Fleischmann *et al.* 2001). However, much of the research findings that were discovered by previous researchers have only been marginally relevant to this research, since they have investigated different product returns, such as re-use (e.g. Kopicki *et al.*, 1993; Kroon and Vrijens, 1995; Fleischmann *et al.*, 1999) or recycling (e.g. Pohlen and Farris, 1992; Brodin, 1997; Goggin and Browne, 2000).

However, since the narrowness of previous research has often been criticised (e.g. Van Hoek, 1999; De Brito *et al.*, 2003a), this research has taken a holistic perspective (closed-loop supply chain management) throughout the study. The research has taken a comprehensive view by incorporating aspects which have been neglected by previous research, such as the interrelationship between players of the closed-loop supply chain. De Brito *et al.* (2003a) confirm that the majority of case studies they reviewed focused on aspects of a real reverse logistics situation but neglected the overall business environment. As a result, insights gained from the cases which were reviewed by De Brito *et al.* (2003) seemed to be one-dimensional. Moreover, De Brito *et al.* (2003a) argue that further field research should aim for mapping the business context including wider information on critical factors within reverse logistics, trade-offs or implications.

Within this dissertation, reverse logistics aspects were related to core return and acquisition for remanufacturing. Issues and uncertainties involved in these processes have been discussed in Chapter Two. The research has shown that the establishment of a collection network for cores and a distribution network for remanufactured products has not been perceived as a major issue within OEM remanufacturing. The research has shown that a condensation of distribution and collection structures, as it is performed by most automotive OEM remanufacturers, does not present the need for a separate reverse logistics system (as summarised in Table 47 in Chapter Six and in Table 49 in Chapter Seven). Moreover, the previous sections of this chapter have demonstrated that reverse logistics is only a significant part of the extended closed-loop supply chain, not of simple in-plant loops. However, communication with industry experts has revealed that this may be different within other countries. In the United States, for example, reverse logistics of commercial returns has by far more effect on business expenditures than it has in Europe and is overall perceived as more significant than reverse logistics for any other product return operation.[71]

In Chapter Two, the integration of forward and reverse flows has also been identified as a major complicating factor within product recovery management. Fleischmann *et al.* (1997) have pointed out that reverse distribution may take the route of the original forward channel, a separate reverse channel or an alternative channel which may be a combination of forward and reverse channel. However, they also confirm that "even if the same actors are involved, integration of forward and reverse distribution may be difficult at the routing level since collection and delivery may require different handling" (Fleischmann *et al.*, 1997, p.4). The closed-loop supply chain models in the previous sections of this chapter have shown that reverse logistics is carried out through forward distribution channels, hence there is a combination of forward and reverse channel. Moreover, the research on OEM engine remanufacturing has shown that core collection is well developed due to the use of the existing dealer network. For OEM engine remanufacturers the integration of forward and reverse flows was therefore not

[71] Commercial returns do generally not require a recovery operation, but are resold after an activity which is often described as 'dust-off' (e.g. Guide and Van Wassenhove, 2003a). This type of return is excluded from the discussion.

perceived as a major issue. This was slightly different for electronic device remanufacturing. Within the electronics closed-loop supply chain, the complexity has been increased through the involvement of suppliers and module producers. It could therefore comprise potential pitfalls for the management of the closed-loop supply chain. However, no particular issues were revealed within the cases under investigation. However, it is likely that this is different for other product groups or case companies.

As a result of this discussion it may be claimed that three main findings with regard to reverse logistics (core return and acquisition) can be derived from this specific research which mainly focused on OEM remanufacturing practices. Firstly, future research needs to differentiate with regard to the actors of reverse logistics systems. This research has found that for OEM automotive remanufacturing, the establishment or appropriate structure of a reverse logistics network has not been perceived as major area of concern within the closed-loop supply chain.

Secondly, not the actual network set-up, but its control seemed to provide more issues for the case companies. It was reported that products were returned through the wrong channels due to confusion at the retail level or that retailers expected rebates for all electronic products they returned, just to name two examples. Hence, future research may consider to present trace and track tools for larger, more complex core collection systems.

Thirdly, it was found that not every product recovery operation requires a reverse logistics system. As the previous sections of this chapter have demonstrated, for simple loops in closed systems, a reverse logistics system is not required.

Uncertainty in Quantity, Quality and Timing of Returns

The supply of cores has been identified as one major uncertainty throughout the research. OEM remanufacturers and independents have both confirmed strong competition for cores. Guide and Van Wassenhove (2001) claim that, until 2001, no published research had considered the management or controlling of product returns.[72]

Instead, the literature suggests that product returns are exogenous problems, with return rates, quality and timing beyond the company's influence (Guide and Van Wassenhove, 2001). The authors also argue that previous research may have wrongly assumed that "the firm passively accepts all returns, and the returns process itself is a black box operation. [...] when product returns are explicitly considered, return rates are assumed independent of sales rates" (p.144). Guide and Van Wassenhove (2001) are therefore taking a point of view which focuses on profit maximisation.

The literature refers to the quality, quantity and timing of raw material supply, including the determination of the ideal purchasing price for cores. However, with regard to this research problem, several distinctions have to be made. The research has demonstrated that there is strong competition for cores. The uncertainty for the OEM did not comprise the determination of the ideal purchasing price, but whether cores could be obtained in the first place. This thesis has identified the main reasons for OEM remanufacturing which will be discussed in Chapter Ten in more detail. Among these were market share and brand protection. Hence, from an OEM perspective, the claims made by Guide and Van Wassenhove (2001) that a company can choose cores selectively has to be confirmed and negated at the same time. On the one hand, an OEM could be more selective with regard to core acquisition by buying back high-quality cores at market prices. However, the 'cleaning of the market' has been one of the OEMs major motives to engage in remanufacturing, whereas direct economic motives have not been identified as a reason for remanufacturing. As a result, the case studies have shown that the OEM does not passively accept all returns, but demands for all cores to return. As

[72] Klausner and Hendrickson (2000), as well as Kumar and Guide (2002) have developed models on take-back prices for used products in order to influence quality, quantity and timing of returns. However, if there is strong competition for cores, the determination of the 'ideal' price may be negligible.

interviewees will further confirm in Chapter Ten, disadvantageous core purchases were acceptable within the Case Company. Although the current industry practice shows what Guide and Van Wassenhove (2001) describe as market-driven system by offering financial incentives for core returns, the situation is different for OEM remanufacturers. Since the direct economic motive (profitability of remanufacturing) could not be considered as one of the main reasons for undertaking the operation, OEMs do not aim to buy back the best cores at the ideal price, but to buy back all cores at any price.

Moreover, this research has shown that, as Guide and Van Wassenhove have argued, the return process is not a black box operation. The case companies have coupled two basic approaches to the exchange process. Firstly, an exchange product may only be purchased if the core is returned. Secondly, there are financial incentives (rebates) to return cores. Guide and Van Wassenhove (2001) have also claimed that product return rates are not independent from product sales rates. This is also true for the case companies which were investigated within this research. In both cases, engine and electronics remanufacturing, for every product sold, a core returned. This may be in form of a warranty replacement, but the distribution of the remanufactured product is still linked to the return of a core.

A far more dominant issue, which has been discovered within this research, is the system loss (scrap) in remanufacturing. Guide and Van Wassenhove (2001) have briefly noted that the high degree of variability with regard to core quality is one of the complicating factors within remanufacturing. This may be eliminated by the application of a market-oriented approach for core returns, which offers a market-related rebate to ensure high core quality. However, Chapter Six has demonstrated the large scrap figures within engine remanufacturing. There are several explanations for these. On the one hand, Case Company A 'ignores' the market-oriented approach as recommended by Guide and Van Wassenhove (2001), since the aim is to collect all cores. On the other hand, one interviewee at Supplier D has confirmed that vehicle manufacturers are generally unaware of market conditions for remanufactured products. This may be due to the fact that remanufacturing is a non-core activity. Moreover, core returns to the vehicle manufacturer may come in large volumes so that average (mixed) calculations

for cores are common and the actual core quality is not considered in the core acquisition process. Chapter Ten will outline this issue in more detail.

9.3.2 Remanufacturing 'Real World' Challenges: Research Results

Inventory Control

Chapter Two has shown that there is a large body of literature on inventory management and control for product returns. However, Guide (2000) has criticised that most of this existing research takes a narrow perspective by only focusing on inventory models which assume that returns are exogenous variables. Van der Laan *et al.* (2003) confirm that most available inventory models take simplified assumptions. They assume, for example, that product returns are independent from demand in order to ensure the tractability of the models. With regard to the criticism made by Guide (2000), the findings of this research will extend the point of view beyond a narrow inventory control perspective. This section also embraces research needs identified by De Brito and Dekker (2003b), who have expressed the need for modelling assumptions which are more suitable for real situations. They have identified one aspect which should be considered in future inventory models, the seasonality of products. This may result in the conclusion that simplified models may neglect specific product characteristics. Previous quantitative research has often focused on the management of 'serviceable' or 'recoverable' inventories. However, the source of inventory management problems was neglected. This section therefore discusses new starting-points for future research on inventory control by addressing the main issues and their sources within an OEM remanufacturing environment.

One of the main problems this research has discovered with regard to inventory management of automotive remanufacturing operations is the tendency for high inventory levels. The engine remanufacturing case study has shown high inventory levels at various places in the supply chain. 13,000 used car engines, the equivalent to an annual production (remanufacturing) output, were stored at the remanufacturing

plant. Moreover, there was a parts warehouse with 31 million parts (remanufactured, new and used). The Global Warehouse stored 8,000 finished products. Chapter Six has noted that these inventory levels not only posed storage problems, but also represented a large financial investment. The key sources or causes for high inventory levels within OEM plants were identified as follows:

- High product variety with regard to customer choice (original product)
- Large number of constructional levels (different engine generations)
- Ability to provide an 'exchange'
- Complete disassembly of the product which results in various conditions of parts (new, remanufactured and used but not yet remanufactured)

These four main causes for issues in inventory management will be discussed in more detail in the following section.

Product variety leads back to product variation of the original product. Wolff (2000) explains that 80% of all cars are customer specified. Each car model can be painted in 25 standard colour and 300 customer specified colours, for example. As a result, Wolff (2000) argues that customer specified mass production and the historic evolution of production structures are the main contributors for complexity. According to one senior manager at Case Company A's Headquarters, the company has experienced a 'model explosion' in the past ten years. Satisfying customer demand by offering personal customisation of mass products has lead to an explosion of variants within car parts and accessories, but also with regard to engines. Each car model is also available with a variety of engine specifications regarding horsepower or fuel type, which creates and increasing number of engine variants. This transfers complexity onto the remanufacturing process. The increase in choice for customers, however, is not supported by all industry experts:

> *More variety and customisation implies increased manufacturing costs and is by no means a guarantee to better satisfying customer needs and desires. This is the situation facing many of the VM. The desire to offer customers numerous choices of appearance, performance, comfort, safety and security is at the expense of escalating complexity and cost in assembly and the supply chain.*
>
> (Alford *et al.*, 2000, p.105).

Amezquita and Bras (1996) agree by claiming that the trend of parts proliferation will continue. It therefore seems as if OEM engine remanufacturing is caught between two aims. On the one hand, there is the product differentiation for new products. On the other hand, product standardisation is required within remanufacturing. As it has been outlined, product differentiation plays a significant role within the automotive industry, but particularly within the luxury car segment. Customers and product designers aim for product differentiation, whereas the aftermarket division craves for standardisation.

Automotive product developers and engineers create new cars from scratch. This 'serial thinking' is dominated by just one aspect: the day of the car's introduction to the market. Aftermarket or remanufacturing issues are not considered. The consequences of product differentiation are visible in increasing inventory levels to serve the aftermarket, as well as high stock-keeping costs.

The team leader for life cycle management, however, explained that it is difficult to find a consensus between the interests of developers and the interests of the aftermarket managers. "Developers always want product differentiation, but the aftermarket segment wants standardisation. Our competitors have the same problem with an 'explosion' of products and variants, but they clear their warehouses much more radically." In fact, the problem does go far beyond the pure aftermarket management side. "Market research has shown us that just 7% of the aftermarket parts generate 90% of the aftermarket profit. The rest of the parts just remains in stock, whereby one part number costs the company €20,000 (warehouse costs and personnel expenditure) per annum", the interviewee further explained.

A solution to this dilemma seems to be the right balance between product differentiation and standardisation, customer orientation and efficient aftermarket management. However, since remanufacturing is perceived as non-core activity, it is rather unlikely that vehicle manufacturers will change their directions in favour of remanufacturing.

The second cause for high stock levels in remanufacturing plants refers to product variety, however, not the variety which stems from increased customer choice, but which refers to the constructional level of the product. Johannes (1995) explains that in a traditional manufacturing environment, there is just one constructional level of the product, whereas within remanufacturing there are several constructional levels of one

product or model, due to previous generations of the product. This research has observed the difficulties of parts proliferation among OEM engine remanufacturers. With regard to the independent sector, Amezquita and Bras (1996) and Hammond *et al.* (1998) have outlined parts proliferation as a major issue among independents. Sections 5.4.2 and 6.4.3 have extensively discussed engine technology variety as well as parts proliferation, which was defined as the making of many variations of the same product, resulting in the prevention of interchanging similar parts or products (see also Amezquita and Bras, 1996).

The third key cause for high inventory levels is the ability to provide an 'exchange'. As the research has shown, the actual process of exchange involves the simultaneous replacement of a core with a remanufactured engine. Interviewees have confirmed that the period between order placement and the delivery of a remanufactured engine (remanufacture-to-order) could take up to thirty days (Section 6.4.3). As a result, finished products had been stored at the Global Warehouse (8,000 engines in 2002). The ability of providing an exchange was observed at VM remanufacturing plants and at remanufacturers who were subcontracted to VMs. The same findings may also be true for large independents. As a result, engine remanufacturers who undertake an exchange process, as it was defined in Chapter Six, are most likely to have high inventory levels at various points in the supply chain. Smaller independents, on the other hand, may charge customers for the service (material, labour, etc.) rather than exchanging a core for a remanufactured engine. However, the investigation of the independent sector was limited with just one case study visit. At this visit, the managing director claimed that around 20 cores were on the premises. However, this independent not only remanufactured passenger car engine cores but also engines from commercial vehicles, tractors and industrial appliances. Hence, for smaller independent remanufacturers, this assumption still has to be confirmed by future research.

The research has demonstrated that the engine remanufacturer sought to replicate mainstream engine manufacturing and therefore completely disassembled the products. The vehicle manufacturer's attempt to replicate mainstream engine production was therefore identified as the fourth cause for high inventory levels.

Chapters Six has outlined that opposed to conventional engine manufacturing which deals solely with new parts, inventory management of a remanufacturing operation needs to consider new, remanufactured and used parts. As a result, there is not just more variety with regard to product characteristics (e.g. new or remanufactured), but also volumes are larger since one particular part may be on stock in different conditions at the same time (e.g. new, remanufactured or used). This resulted in a 31 million parts warehouse at Case Company A's remanufacturing plant. However, as Amezquita and Bras (1996) have argued that "mass production practices are not compatible with large product varieties" (p.35). Consequently, rather than forcing existing manufacturing practices onto remanufacturing operations, a new and more appropriate approach should be developed for larger remanufacturing operations. Future research may therefore seek to investigate whether the replication of mainstream engine manufacturing is appropriate for a remanufacturing environment – not solely from an inventory management perspective, but also from a process flow perspective.

Recovery Planning and Control

Product diversity does not only have an impact on inventory management, but also on the recovery process itself. As an example, interviewees at the remanufacturing plant reported about one car model which had been introduced to the market in February 2002. After four months, there were four different engine variants. One of the earliest engine variants had already been remanufactured at the time of the research visit (June 2002). This research has found that product proliferation impedes the remanufacturing process. Chapter Five has outlined the difficulties within a typical engine manufacturing process in which manufacturers aim at producing one family of engines with the same core block, crankshaft and cylinder head in order to put the engine family through the same machining lines. However, within remanufacturing, these difficulties are multiplied. As Chapter Six has demonstrated, Case Company A re-assembled engines in relatively small batch sizes. Amezquita and Bras (1996) confirm that current remanufacturing processes are heavily batch oriented. Due to low remanufacturing volumes and high product variety, current remanufacturing practice resembles a craft production system (Amezquita and Bras, 1996). This research has shown that craft

production is still common practice, for example in the disassembly and quality control processes (as outlined in Section 6.4.1).

> *Most automotive parts remanufacturers (and other remanufacturers) still rely on craft production systems to handle the variability in the number of parts to be remanufactured and the variability inherent in refurbishing operations due to wear differences.*
>
> (Amezquita and Bras, 1996, p.38)

Chapter Two has further outlined that for many automotive remanufacturers, high automation is technically not feasible. As a result of high product variability and low batch sizes, tool changing times are high. Moreover, most recovery steps require skilled workers who are able to deal with different product variants during one shift. A potential approach to problem-solving could be an even stronger emphasis on platform design of engines so that parts may become more interchangeable and tools as well as machinery could be utilised for more parts.

However, there are several aspects which interfere with significant engine design changes. Firstly, this research has demonstrated that there is no communication between engineers and designers from new engine manufacturing and engineers from remanufacturing. It has also been outlined that designers of new parts do not consider remanufacturing or aftermarket issues. Moreover, for large corporations, such as Case Company A, there seems to be no intention to changing current industry practice. As previously outlined, remanufacturing is perceived as non-core activity within automotive OEM remanufacturers. Its importance has not grown in the past decade. Case Company A's managing director of the remanufacturing plant has explained that despite the vehicle manufacturer's overall increases in engine production, engine remanufacturing has produced consistent volumes over the years (as shown in Appendix J, for example). As a result, engine remanufacturing may remain a non-core activity. For remanufacturing plants owned by vehicle manufacturers, this may indicate no significant changes to current practice.

As second issue related to the recovery process can be summarised as the strong dependency on external service providers and suppliers. Chapter Six has shown that within Case Company A, delivery times for remanufactured engines were very high and ranged between 20 and 40 working days. The long delivery times were influenced by internal and external service providers (remanufacturing) and suppliers (new parts). Only 30% of all parts were remanufactured by the Case Company's plant. Within external remanufacturing, the critical aspects were long delivery times. Representing a non-core business, the acquisition of new parts has become challenging, too. The remanufacturing plant therefore not just represented a low-volume non-priority client, but priority was also given to supplying the assembly line for new engines.

There were several strategies which engine remanufacturers applied to limit the uncertainty of parts supply. On the one hand, a common practice is the so-called 'over-stripping', which indicates that more cores are disassembled that needed in the re-assembly process. Johannes (1995) further explains that the remanufacturing process can make use of alternative parts to replace unavailable parts. In most cases, these alternative parts are taken from other used products with a different constructional level. These parts are then transformed so that they can replace the unavailable part. A third approach is the accumulation of high inventory for buffering. As it has been observed within the independent sector, remanufacturers may 'manufacture' their own parts, which is a practice which could not be confirmed for OEMs.

As a result of these observations, it was concluded that there is scope for the application of lean principles. Amezquita and Bras (1996) have identified 'waste of overproduction', 'waste of inventories', as well as 'waste of transporting' within automotive clutch remanufacturing. Hence, there is the need for the more detailed identification of non-value added activities within engine remanufacturing in order to eliminate 'wastes'. Guide *et al.* (1999) confirm:

> *Safety stock in this environment does provide some limited protection against material recovery variation, but not the amount of coverage expected. Hence, the benefits of using safety stock to provide stability to remanufacturing schedules may be limited.*
>
> (Guide *et al.*, 1999, p.228)

A second approach to achieve improvement of the above issues is the development of a specific demand forecasting tool. The research has discovered that, at the time of the research, forecasting was not practiced within the Case Company. Interviewees gave several reasons for that. They were asked why future demand for remanufactured products could not be based on the number of cars on the road. One interviewee explained that forecasts for remanufactured engines based on the amount of cars on the road have proved too complex and time-consuming. Furthermore, the determination of cars on the road is difficult in itself, considering the migration of cars into foreign countries, for example. Moreover, there are certain cases which are generally difficult to forecast, such as warranty defects. Section 6.4.3 has outlined in detail that reliable data for demand forecasting could only be obtained from fleet managers and the retail level. However, with regard to fleet management, the circumstances under which these vehicles operate differentiate from the average car in the market. In the case of real consumption data (retailers), the complexity of requesting information would not justify the benefit of more accurate forecasting of the demand for remanufactured engines. However, the author assumes that a further issue with regard to forecasting was based on the fact that the engine remanufacturer recovered the engines and the Global Warehouse distributed the goods. The remanufacturer therefore has no access to real market demand, but remanufactured according to the orders placed by the Global Warehouse.

9.4 Summary

Table 61 summarises the research findings of this chapter. These findings may provide starting-points for future research in the area.

Aspect(s)	Findings
▪ Collection structure complexity ▪ Integration of forward and reverse flows	▪ Future research needs to differentiate between types of actors, such as OEMs or independents ▪ More emphasis has to be put on return flow control of larger, more complex return systems (trace and track tools) ▪ Not every product recovery operation requires a reverse logistics system
▪ Uncertainty of quality, quantity and timing of returns	▪ For OEMs, the acquisition of high quality cores at the ideal price ('market-oriented approach') is not the main objective ▪ The 'cleaning of the market' is top priority for OEMs ▪ For large remanufacturing businesses, the market-oriented approach is difficult to implement; mixed calculations are standard ▪ Disregarding the market-oriented approach results in high scrap rates ▪ Coupling of two approaches to influence returns: a) process of 'exchange' b) rebate ▪ Product return rates are not independent from product sales rates
▪ Inventory control	Main causes for high inventory levels in OEM plants: ▪ High product variety due to product customisation ▪ Large amount of constructional levels ▪ Ability to provide 'exchange' ▪ Complete disassembly of the product
▪ Recovery planning and control	OEM remanufacturing characteristics: ▪ Small batch sizes ▪ Low automation ▪ Strong dependency on external service providers

Table 61: Summary of Discussion on Research Findings

9.5 Conclusion

This chapter has linked Research Questions 1 and 2 with the data presented in Chapters Six, Seven and Eight and has presented, discussed and analysed the results. Since previous research has often presented a mixture of in-plant and supply chain models, this research has, from the beginning, clearly differentiated between holistic closed-loop supply chain models (Research Question 1) and in-plant models (Research Question 2). The first research question therefore asked for the identification of closed-loop supply chain structures that are relevant to the automotive industry. The first step to answering Research Question 1 was achieved by the development of a terminological framework as well as the creation and discussion of two conceptual closed-loop models. The first conceptual model showed simple loops (Figure 29), the second model illustrated extended loops (Figure 30). The research question was fully answered by the presentation and discussion of the two closed-loop supply chain structures that are relevant for remanufacturing operations undertaken by the OEM (Figures 31 and 32).

The second research question referred to the identification of an appropriate remanufacturing process structure for the automotive industry. Research Question 2 could be partially answered by the discussion of remanufacturing process structures for engines (Section 6.4) and electronic devices (Section 7.6.2). Chapter Nine further elaborated on the characteristics of relevant remanufacturing process structures by discussing the issues and obstacles related to the management of remanufacturing processes. The discussion firstly evolved around the issues that were identified in the literature (Chapter Two). However, this research found that some aspects taken from the literature only played a minor role within this case research. Consequently, the 'real-world' challenges of OEM remanufacturing processes were presented and summarised in Table 61. They provide starting-points for further research in the field, an aspect which will be further discussed in Chapter Eleven. However, it needs to be considered that these findings are specific to the Original Equipment Manufacturer, the automotive sector and the case companies that were investigated. Future research therefore needs to examine whether these results are also valid for the independent remanufacturing sector or other product groups within the automotive industry.

Chapter Ten
Identification of a Rationale for Automotive Remanufacturing

10.1 Introduction

This chapter links the three research questions that investigated the rationale for automotive remanufacturing (Chapter Three) to the presentation of results in Chapters Six to Eight. In other words, this chapter seeks to confirm or decline the three main reasons for product recovery, which were identified as ethical and moral responsibility, environmental legislation and the direct economic motive. It will become clear that initial research expectations with regard to the motives for product recovery differ from actual research findings. As a result, motives for product take-back and recovery have to be readjusted and redefined for the automotive sector.

This research makes a contribution by not only testing reasons for remanufacturing that were taken from the literature, but also by providing the 'true' reasons for automotive remanufacturing as they were identified for the case companies and for the specific product groups. In addition, the chapter seeks to explain why the research outcomes differ from the research expectations, but particularly emphasises why the main motives

for product recovery that were taken from the literature did not fully apply to the case companies and to the companies that were surveyed.

This chapter is divided into two parts. Firstly, the three reasons for product recovery (research questions), as they have been identified in the literature, will be examined with regard to remanufacturing and either confirmed or declined for OEM automotive remanufacturing.

Secondly, the research findings, the newly discovered motives, are presented and discussed. Overall, this chapter seeks to account for three different perspectives, namely engine remanufacturing, electronic device remanufacturing and OEM remanufacturing. Since this research has only marginally investigated the independent remanufacturing sector, only slight reference is made to independent remanufacturing. Moreover, the chapter emphasises engine remanufacturing rather than electronic device remanufacturing. There are two reasons for this. Firstly, as outlined in Chapters Six and Seven, there has been more historical data and evidence for engine remanufacturing than there was for electronic device remanufacturing. Secondly, the author's stay within the facilities of the two electronics suppliers was significantly shorter than the research within the engine remanufacturing plant.

10.2 Reasons for Remanufacturing–Reconciliation of Research Questions

This section discusses two main aspects. On the one hand, it reveals whether initial assumptions and expectations can be confirmed by the research findings. On the other hand, new research findings, which have only been marginally observed by previous research, will be presented.

As already noted in Chapters Two and Three, there are diverse reasons for companies to undertake product recovery operations. Within the closed-loop supply chain literature and the literature from the environmental social sciences, the major motives for remanufacturing have been identified as product take-back legislation, the direct economic motive, as well as ethical or moral responsibility. From a more specific and empirical perspective, Lund (1984b) summarises four further reasons for an OEM to engage in remanufacturing, which all result in high profitability: increasing customer

loyalty, information feedback to product design, extension of the product price range and market protection. These very specific reasons for remanufacturing, however, have been largely neglected in academic research, but will be discussed later in this chapter. Lund (1984b) justifies the importance of those additional motives:

> *Original equipment manufacturers (OEMs) that go into remanufacturing as part of their business do so for a variety of reasons, all of which boil down to one fact: it is good business. Not only is the OEM more likely to retain a loyal customer by offering a good trade-in value for the old unit, but it can also give the customer a wider price range on the replacement unit. In addition, the OEM learns first hand what goes wrong with its product during use. This information can be used to improve product designs of future models and to device modifications that will prevent similar problems in remanufactured units. In other instances the OEM may merely act defensively, to discourage entry of independent remanufacturers of its products. These reasons are important to OEM remanufacturing operations, but a key factor in virtually every remanufacturing operation it is highly profitable. During the recent recession the head of the remanufacturing division of a major U.S. firm remarked that his division was the only part of the company that kept the firm from losing money.*
>
> (Lund, 1984b, p.13)

In this section, the reasons for remanufacturing which have been taken from the academic body of literature are examined with regard to their applicability to the automotive remanufacturing sector. The first product group under investigation, passenger car engines, had been selected due to the fact that it was among the first automotive products to be remanufactured. Electronic component remanufacturing, on the other hand, was, at the time of the research, still at a very early stage of its remanufacturing life cycle. As a result, the driving forces for engine remanufacturing and electronic device remanufacturing differed. It is often assumed, for example, that mechanical remanufacturing began during the Depression and gained further significance during the Second World War (Environmental Protection Agency, 1997). However, as one interviewee recalls, Case Company A's engine remanufacturing activities, which developed into a high-volume remanufacturing operation in the middle of the 1980s, were based on different motives.

This research has found that very likely, the first rationale for engine remanufacturing within the OEM case study was the high rate of engine breakdowns among previous

engine generations. Consequently, the Vehicle Manufacturer needed to provide replacements. Remanufacturing was therefore initially defined as an operation that provided replacements in a short period of time and at a reasonable price. However, since technology has largely improved, it is assumed that this basic reason for engine remanufacturing has become less significant.

With regard to methodology, this chapter is mainly based on interviews results from the four phases of research (see Section 4.3.3). As outlined in Chapter Four, in course of the interviews, initial questions phrased broadly through the enquiring about motives for remanufacturing: "What are the motives of your company to provide exchange parts?" and "What are the main reasons for the company to undertake remanufacturing"? As a result, no limitations were given to answers as no a priori categorisation of answers was provided. It was assumed that this way of interviewing allowed interviewees to outline motives for remanufacturing that were perceived as most relevant in the 'real world'. Only after interviewees had outlined 'their' motives, specific enquiries were made with regard to the motives incorporated within Research Questions 3 to 5. Several conclusions were drawn from this specific way on interviewing. It was assumed that interviewees would refer to the most important and most relevant motives first. In cases where interviewees extensively outlined other reasons for remanufacturing than those found in RQs 3 to 5, the author assumed that those motives were perceived as predominating in the OEM remanufacturing sector. In other words, there were two ways in which a pre-defined motive (as the three motives within the Research Questions) could be excluded as a reason for OEM automotive remanufacturing. Firstly, the motive was not mentioned by the interviewee at all. Secondly, after a specific enquiry through the author, the motives from Research Questions 3 to 5 were not confirmed as reasons for remanufacturing within the company b the interviewee. With regard to the following sections it is therefore important to note that not only the denial of a specific motive for remanufacturing has played a significant role in reaching the conclusions from interview results, but also the fact that an interviewee did not mention a specific motive or elaborated on more significant reasons has lessened the importance of pre-defined motives. Please note that several direct quotes from interviews refer to more than one motive for automotive remanufacturing. However, the structure of the chapter does not

allow a repetition. Those quotes are therefore outlined within one section but may also refer to another section within this chapter.

10.2.1 Ethical and Moral Responsibility

Research Question 3 asked whether moral or ethical responsibility is a motive for automotive remanufacturing: Is automotive remanufacturing induced by the corporation's needs to be morally or ethically responsible for its actions?

Chapter Three has presented the 'pillars' of corporate social responsibility, or, the 'range of business responsibilities' as identified by Carroll (1991). These were summarised as economic responsibility ('be profitable') as basis of the four additional responsibilities, the legal, ethical and philanthropic responsibility (Carroll, 1991). The legal and economic responsibilities will be discussed in isolation in the subsequent sections of this chapter. However, they will be examined as reasons for remanufacturing, but not with the intention to represent a pillar of corporate social responsibility.

This section aims to outline what has been described as 'ethical responsibility' by Carroll (1991). In other words, this section examines to what extent standards, norms or expectations, which are seen as 'fair' or 'just' by stakeholders (e.g. consumers, employees or shareholders) have influenced the establishment of automotive remanufacturing operations. Holliday, C.O. *et al.* (2002) argue that corporate social responsibility results in three key benefits, including improved brand value and reputation, improvements in human capital and revenue generation. This section, however, does not examine the key benefits or results of CSR, but questions ethical responsibility as a motive for automotive companies to undertake remanufacturing.

Within this research, the ethical or moral reasons that may induce product take-back and remanufacturing in the automotive sector have been described as 'pressure from society' and 'extended producer responsibility' in the questionnaire survey (see Chapter Eight).

This aspect also incorporates societal pressures on companies to conserve resources, such as energy, material and labour. On the one hand, a company may seek to differentiate its position in the market by offering a 'green' product range. This also protects the corporation from public criticism. On the other hand, producer responsibility may prevent future liabilities. However, the empirical chapters (Chapters Six, Seven and Eight) have shown that this could not be fully confirmed for the case companies. There are several reasons for that.

Firstly, within the openly phrased questions, *none* of the interviewees mentioned the topics of 'ethics', 'green consumerism', the 'green marketplace', 'pressure from society', or 'environmental responsibility' as motives for OEM automotive remanufacturing. As previously outlined, it was therefore assumed that motives which were not mentioned by interviewees themselves were not considered as very significant 'real-world' drivers for OEM remanufacturing. Within Company A's remanufacturing plant, the environmental contribution made by engine remanufacturing was perceived as nice 'side effect'. However, interviewees confirmed that environmental, ethical or moral responsibility was neither the reason for the OEM to remanufacture nor for the customer to buy the products:

> *Our main customer target group for remanufactured engines [passenger cars and light commercial vehicles] comprises taxi and shipping companies as well as fleet owners. The police are a good case in point, too. These customers have one thing in common: they wear out engines quickly.*[73]

A second interviewee at the same location adds:

> *The only customers that are prepared to purchase remanufactured engines are taxi or shipping companies, such as UPS. All others don't want to build a practically new engine into an old 'shell'.*[74]

[73] Quoted from the interview with the Manager for Core Warehousing and Dismantling at Case Company A's remanufacturing plant, June 2002, translated from German.
[74] Quoted from the interview with the Manager for Cleaning and Identification Processes at Case Company A's Remanufacturing Plant, June 2002, translated from German.

With regard to electronic device remanufacturing, interviewees at Case Company D confirm the absence of the 'ethical' or 'green' consumer:

> *Our remanufactured electronic devices are almost exclusively used for under-warranty cases.*[75]

> *Electronic devices are not remanufactured because of environmental reasons or the ELV Directive, but because of cost savings made within warranty cases. Both parties save warranty costs: the VM and the supplier.*[76]

In addition, interviewees confirmed that they had not perceived any pressure from society with regard to environmental responsibility that would have driven or supported OEM automotive remanufacturing. In fact, several respondents claimed that there is generally little known about remanufactured products amongst the broad mass of 'common car users'. The Manager for Cleaning and Identification at Company A's Remanufacturing Plant explains:

> *The important thing is to point out the advantages of remanufactured products to the customers. Hardly any normal customer knows about remanufactured engines. But the truth is that subsidiaries rather sell a new car than a remanufactured engine.*[77]

Another interviewee confirms:

> *An environmental responsibility or an environmental rationale has zero influence on our remanufacturing efforts. OEM remanufacturing is also not undertaken because of the ELV Directive. As I have mentioned before, the most important drivers are spare parts supply and warranty.*[78]

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[75] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at Case Company D, July 2003, translated from German.
[76] Quoted from the interview with the Manager for IT Integration at Case Company D, July 2003, translated from German.
[77] Quoted from the interview with the Manager for Cleaning and Identification Processes at Case Company A's Remanufacturing Plant, June 2002, translated from German.
[78] Quoted from the interview with the Product Manager for Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, September 2002, translated from German.

However, a second interviewee adds that even though environmental responsibility has not been a motive for automotive remanufacturing and for OEMs at the time of the research, its significance may increase in near future.

The relevance of environmental responsibility as a motive for automotive remanufacturing has also been investigated within the questionnaire survey, with the aim of broadening and generalising the results by including the independent remanufacturing sector. Within the questionnaire, this motive was examined in form of the 'environmentally conscious customer'. Three respondents of the questionnaire claimed that an 'environmentally conscious customer' is the most important aspect which creates growth. While this is not a representative result, it is surprising that a total of ten respondents rated this aspect as general creator of growth. As noted in Chapter Eight, the majority of respondents consisted of independent remanufacturers. The author therefore questions the strength of this motive, due to the 'rational' decision-making process outlined by Durdin (2004).

> *A consumer's decision to repair a vehicle is influenced by the residual (i.e. resale) value in the vehicle. If the cost of the remanufactured engine plus the fitting charges (which is often the higher cost) is of similar value to the resale value, the consumer will be reluctant to commit to the repair, but will use the money to buy another vehicle.*[79]

It may therefore be assumed that the results from the questionnaire survey were slightly biased in a way that respondents thought this particular answer would be 'politically correct' in times in which environmentalism seems to be a key factor within any industry sector. Publications in practitioner circles, such as the article in the Vehicle Electrics and Electronics (2003) (cited in Chapter Three), in which it is explained that the environmental lobby has never looked favourably onto the remanufacturing industry, confirm this assumption.

[79] Quoted from personal communication (E-Mail) with Tim Durdin, the Managing Director of Wealdstone Engineering Ltd. in Rushden, UK, January 2004. See full interview in Appendix G, Key Interview 4.

The second main reason why ethical or moral responsibility could not be confirmed as reason for OEM automotive remanufacturing refers to case companies' promotion of environmental friendliness of remanufactured products. In course of the research, it became clear that there is a gap between the communication with 'outsiders' (in form of environmental publications) and internal communication. The author assumed that if ethical or moral responsibility, which may (with regard to this research) be expressed in form of environmental responsibility, is a reason for the OEM to remanufacture, it would be promoted extensively within annual environmental publications, for example. As a result, several annual environmental reports of the case companies, from other players in the market and from the commercial vehicle sector (in which remanufacturing is a vital part of the industry) were reviewed. In course of the review and through a comparison with interview data and documentation obtained from the case companies, the following discoveries were made.

Case Company A promoted the energy and material savings made through remanufacturing in publications related to their remanufacturing plant. However, group-wide annual reports of several years that were reviewed by the author, neglected to mention remanufacturing. On the other hand, internal company reports obtained from the Product Manager for Remanufactured Parts (at Company A's Headquarters) emphasised the company's 'impulses' or 'incentives' of providing remanufactured (exchange) parts. The Company's main motives for remanufacturing were therefore *internally* promoted as the following key aspects:[80]

- *The withdrawal of recoverable parts and material* [from the market]
- *Cost-saving alternative of a replacement/spare part*
- *Obligatory supply of spare parts for 15 years*
- *Reliable and low cost source of warranty parts*

However, if remanufacturing makes a contribution to environmental protection, as it has been confirmed within the literature (see Chapter Three), the question arises why

[80] Quoted from internal company documents obtained alongside the interview with the Product Manager for Remanufactured Parts at Case Company A's Headquarters, February 2003, translated from German.

industry players do not seize the opportunity to promote their eco-friendly actions. There are a number of explanations. Firstly, it may be the case that remanufacturing saves material and energy, however, its overall contribution may, in fact, be small compared to environmental measures undertaken in high-volume, 'conventional' automotive manufacturing plants (e.g. efficient use of resources or environmentally-friendly waste management).

A second reason why the industry does not promote the environmentally-friendliness of remanufacturing may be the increasing production of 'throwaway' car parts, a trend, which has been pointed out by several interviewees.

> *This is the smallest car engine manufactured and built into cars by our group at the moment. It cannot be remanufactured as there are a lot of parts made from plastic that can only be used once. The engine would get partially destroyed in the disassembly process, too. In addition it is a very cheap engine to manufacture from new parts.*[81]

In other words, by promoting their remanufactured products, automotive companies endanger to be discovered as producers of non-recoverable parts, such as non-remanufacturable car engines. The Managing Director of a major UK-based remanufacturer provides a further explanation during the interview:

> *The environmental reports are usually issued by the PR departments, so they are looking for items of public interest, whereas remanufacture is not 'sexy'. By weight in the vehicle and by energy saved, remanufacture is extremely significant. I just wish the Treasury would reward the energy saved in tax allowances in the same way that it is encouraging Alternative Energy sources such as wind and wave power!*[82]

[81] Quoted from the interview conducted with the Manager for Core Warehousing and Dismantling (from the remanufacturing plant) while observing the engine manufacturing processes at Case Company A's manufacturing plant for new engines, June 2002, translated from German.
[82] Quoted from personal communication (E-Mail) with Tim Durdin, the Managing Director of Wealdstone Engineering Ltd. in Rushden, UK, January 2004. See full interview in Appendix G, Key Interview 4.

Thirdly, the automotive industry has always focused on the making and distribution of new products. This is also valid for the aftermarket, in which new products are distributed for the purpose of replacement. As a result, the whole industry is structured to suit the needs of new parts production and distribution. The return and recovery of used products was not anticipated to be a part of this structure. Remanufacturing may be seen as 'less glamorous' than the distribution of new cars and may even result in negative brand image. Chris Hancock, the editor and publisher of several industry journals has even observed a 'contra-remanufacturing' attitude from VMs towards the independent sector:

> *The attitude to remanufacturing has never been positive* [...]. *The VMs and to a degree the OEMs prefer to produce non-remanufacturable products. The only problem is as technology advances with the original product so it does in the aftermarket.*[83]

He even admits that there is an 'anti-remanufacturing' attitude amongst multinational companies within the automotive sector (see also interview quote in Section 10.2.2).

Ferrer and Guide (2002) confirm that a pure ethical reason can never be the main motive for remanufacturing. They furthermore argue that companies need to focus on investing into their core-activities, rather than offering eco friendly products as part of ethical responsibility.

> *Firms are often encouraged to offer environmentally friendly products (for example, remanufactured products) as part of being a good citizen. However, this is an unrealistic expectation since a rational firm will only engage in profitable ventures, those that create shareholder wealth. Further, it may not be reasonable for every original equipment manufacturer (OEM) to engage in re-use activities. The fastest growing firms in electronics and telecommunications may need all the available capital to invest in core activities as well as research and development.*
>
> (Ferrer and Guide, 2002, p.513)

[83] Quoted from personal communication (letter) with Chris Hancock, the editor and publisher of several practitioner and industry journals such as *Engine Repair and Remanufacture* and *Vehicle Electrics and Electronics: Diagnostics and Emissions*, Rye, UK, January 2004. See full interview in Appendix G, Key Interview 5.

Ferrer and Guide (2002) therefore claim that the decision-making process with regard to an engagement in recovery activities should be based on a thorough costs and benefits analysis. In course of the research, there has always been the question about the strength of the environmental, social or moral motives behind product take-back and remanufacturing. One interviewee, who was questioned within the electronic component remanufacturing case study, concluded:

> *The idea of being environmentally-friendly has no influence on remanufacturing at all. Also, automotive remanufacturing is not undertaken because of the ELV Directive.*[84]

Concluding, ethical or moral responsibility (Research Question 3) could not be confirmed as a motive for remanufacturing with regard to the specific case companies the specific product groups that were investigated (engine and electronic devices) and the automotive sector. However, it is likely that the relevance of an ethical or motivation for remanufacturing may differ within other industries or may be valid for other products within the automotive sector. In addition, as one interviewee has outlined, ethical or moral responsibility may not have been of significance at the time of the research, but main increase in importance in future, given continuous environmental degradation, for example.

10.2.2 The Impact of Product Take-Back and Recovery Legislation

The fourth research question sought to enquire the role of (European) product take-back legislation with regard to automotive remanufacturing. Research Question 4: Is automotive remanufacturing induced by product take-back and recovery legislation, such as the European ELV Directive?

In order to fully answer this research question, the first step was to identify which Directive is affected with regard to automotive electronics. It has been unclear whether an automotive electronic device that has been taken out of a car would fall under the

[84] Quoted from the interview with the Team Manager for Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, September 2002, translated from German.

WEEE Directive or the ELV Directive. However, the interpretation of the law even seemed to be confusing for experts.

According to the Department of Trade and Industry (Norgrove, 2004), electronic devices in cars, such as telephones, television sets and hi-fi systems, if in an ELV, are seen as a part of an ELV and count towards the vehicle's weight (i.e. more weight towards recovery). In this case, they fall in the category ELV Directive. However, if parts are removed from the car during the life cycle, these count towards the WEEE Directive and have to be dealt with accordingly. The point in time when a vehicle becomes an ELV is the issuing of the ELV certificate by the authorised treatment facility.

An enquiry was also sent to the European Commission's Directorate-General for environmental matters which resulted in the following interpretation of the law.

> *The Directorate-General holds the view that if an electronic device was primarily designed for an application within cars (e.g. car radios), it falls under the ELV Directive. Devices which were not primarily designed for an application within cars (e.g. mobile phones which could also be used in the car whilst driving), fall under the WEEE Directive.*[85]

The ELV and WEEE Directives represent two distinctive pieces of law, but there are a number of commonalities. Both Directives are largely based on a waste disposal problem in the EU. Also both Directives target the producer of the goods. Hence producers have to provide for the financing of collection, treatment and recovery of their end-of-life products. This section therefore refers to Research Question 4 by asking whether product take-back and recovery legislation has been a motive for companies to undertake automotive remanufacturing operations. The two main case studies which focused on OEM remanufacturing have therefore investigated the 'producer' as it is defined by the Directives. It has to be noted that this section does not aim to demonstrate if companies comply with the law or seek to fulfil what has been defined as legal component of CSR or 'legal responsibility' by Carroll (1991). In other words, this

[85] Quoted from personal communication (enquiry via E-Mail) with the Directorate-General for Environmental Matters of the European Commission in Brussels, Belgium, February 2004, translated from German.

section seeks to unravel the power of legislation as a reason for remanufacturing rather than the compliance of companies with environmental regulations.

With regard to the implementation of environmental policies, the power of legislation has already been confirmed by Murphy and Poist (2003). While it is a different discussion to which extent remanufacturing contributes to environmental protection, Chapter Three has raised the question if legislation is a major reason for conducting remanufacturing activities. The role of product take-back legislation has been identified as a major reason for product recovery operations and remanufacturing by main contributors in the field (e.g. Feldman *et al.*, 1999; Guide, 2000; Linton, J.D, 2000).

In the course of the research, several aspects were discovered which indicated that legislation has never been a reason for automotive companies to undertake remanufacturing. Firstly, Chapter Two has illustrated the historical development of automotive remanufacturing in the United States and Europe. There were a variety of factors which seemed to have nurtured the development of a remanufacturing sector, such as the material scarcity during the Depression and the Second World War or the demands from the racing industry. As a result, the remanufacturing sector has developed due to a variety of reasons, which had an impact long before environmental degradation was perceived as a worldwide issue. In Europe, where remanufacturing activities seemed to have emerged slightly later than in the US, the first independent engine remanufacturing company was established at least 60 years before the first European automotive product take-back and recovery regulation. With regard to the WEEE Directive and electronic device remanufacturing, it has to be emphasised that the case companies B, C and D began their electronic device remanufacturing activities in the late 1990s. This was a point in time, when the WEEE Directive has not yet been in force.

> *We have been repairing radios since decades and remanufactured them since approximately 10 years. Since the late 1990s, we have also been remanufacturing head units.*[86]

Moreover, as outlined above, the WEEE Directive does not cover automotive electronics. Instead, it refers to large and small household appliances, telecommunications equipment and consumer equipment, for example. Hancock (2004) confirms:

> *Engine remanufacturing has been operating since before the Second World War and has been way ahead of its time in recycling. Just leaving the fast moving automotive industry and engines used in other applications such as marine, industry, agriculture, commercial vehicles, classic cars, etc. are kept going through remanufacturing almost indefinitely.*[87]

In addition, the ELV Directive does not seem to cover two cases which are relevant to this research. On the one hand, the Directive refers to the car as a whole. Hence, an environmental contribution which is made by the recovery of certain components during a car's life cycle is neither covered by the Directive nor accredited to the original producer or remanufacturer in any way. An enquiry with the European Commission did not confirm that remanufacturing during a car's life cycle is credited to any industry player. In fact, the ELV Directive only refers to 'whole' vehicles which have become 'waste'.

Question: Can I argue rightly that the ELV Directive refers to the car as a whole? Does this also mean that any contribution made by re-use, recycling or remanufacturing during a car's life cycle is not considered in the Directive?

Response: *The aims of the ELV Directive with regard to reuse, recycling and recovery refer to the point in time at which the car becomes waste. The Directive furthermore requires that waste or used parts from car repairs have to be collected and treated accordingly.*[88]

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[86] Quoted from the interview with the Manager Stock and Supplier Management for Electronic Devices at Case Company B, February 2003, translated from German.
[87] Quoted from personal communication (letter) with Chris Hancock, the editor and publisher of several practitioner and industry journals, Rye, UK, January 2004. See full interview in Appendix G, Key Interview 5.
[88] Quoted from personal communication (E-Mail) with the Directorate-General for Environmental Matters of the European Commission in Brussels, Belgium, February 2004, translated from German.

In fact, one interviewee confirmed the above statements. The original manufacturer is not credited for the environmental contribution made by remanufacturing activities:

> *I am not aware that vehicle manufacturers can 'score'* [with regard to environmental take-back legislation]. *Particularly, since cores do not necessarily return to the vehicle manufacturer and the remanufactured parts are not imperatively distributed by the original manufacturer.* [...] *for the rest, the remanufacturing of valuable used parts is not a result of environmental considerations, but takes place because there is a profitable market.*[89]

It may therefore be assumed that there is no direct link between the original manufacturer's obligations to take back the products for product recovery and the environmental contribution made by the remanufacturing sector. There does not seem to be an 'environmental balance sheet' in which the environmental (and therefore legal) contribution of automotive remanufacturing is recorded and accredited. The Managing Director of one of the main players in the automotive remanufacturing market in the UK confirms an awareness of the ELV Directive. However, environmental take-back and recovery laws do not seem to have a significant impact on the remanufacturing operation, as the author assumes that industry players would be more aware of the Directive and its role as 'driving force':

> *I'm afraid I cannot help you here, as I only know the broad outline of the ELV directive and not the detail.*[90]

Chris Hancock outlines two more reasons why environmental legislation does not seem to support remanufacturing or could be considered as motive for companies to establish remanufacturing operations. Firstly, he has observed a certain resistance from multinationals towards implementing the Directive, in particular with regard to recycling. Secondly, the independent remanufacturing sector has been operating for decades, in other words, long before environmental legislation emerged.

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[89] Quoted from personal communication (E-Mail) with Thomas Kobudzinski from Department for Public Relations at the Gesamtverband Autoteile-Handel e.V. (German representation of interests – independent parts distributors) in Ratingen, Germany, October 2003, translated from German.

[90] Quoted from personal communication (E-Mail) with Tim Durdin, the Managing Director of Wealdstone Engineering Ltd. in Rushden, UK, January 2004. See full interview in Appendix G, Key Interview 4.

> *As the majority of companies in remanufacturing are small, they do not have the power multinational can apply on Government and politicians. With the later as big employers the last thing they want is to loose these companies to developing countries. Remanufacturing is of little interest to the multinationals preferring to supply new. Even the ELV Directive does not specify recycling within the automotive industry. In fact they are keen to see old product going anywhere other than back into the industry. There is no powerful voice standing up for remanufacturing. It will only happen when as with the fridge fiasco it hits the powers that be. To my knowledge there has been little research and development let alone finance in encouraging recycling within the automotive industry.*
>
> [...]
>
> *Engine remanufacturing has been operation since before the second world war and has been way ahead of its time in recycling. Just leaving the fast moving automotive industry and engines used in other applications such as marine, industry, agriculture, commercial vehicles, classic cars etc. are kept going through remanufacturing almost indefinitely.*[91]

However, the environmental contribution of this industry sector should be recognised. The questionnaire survey has demonstrated that legislation may also have destructive effects on the automotive remanufacturing sector. Six respondents noted that legislation, such as environmental regulations or labour law, may be a 'most important factor' for restricting growth.

The argument of legislation being a reason for remanufacturing is weakened by the fact that this dissertation has discovered further significant and predominant reasons for vehicle manufacturers to undertake engine remanufacturing, such as the securing of spare parts over the whole car life cycle, as well as market share and brand protection (see also Section 10.3). These reasons were perceived as more dominant by interviewees than other motives for engine remanufacturing. In fact, it may be argued that interviewees had not considered legislation as a reason for engine remanufacturing, since the interviewer had to enquire about this aspect specifically.

[91] Quoted from personal communication (letter) with Chris Hancock, the editor and publisher of several practitioner and industry journals, Rye, UK, January 2004. See full interview in Appendix G, Key Interview 5.

A third point which indicates that legislation may not be a reason for engine remanufacturing is the more general result from the questionnaire survey. Seven respondents identified legislation as 'most important factor' for growth. In other words, they perceived that current and future legislation would have a positive impact on growth within the automotive remanufacturing sector. Although, this is evidence to claim that legislation may support remanufacturing, it did not seem to be the reason which resulted in the establishment of the companies within the independent remanufacturing sector. Respondents claimed that 'making profit', 'expansion of existing business', 'family', 'hobby or expertise' as well as 'business opportunity' were the main reasons for the set-up of their remanufacturing businesses. None of them mentioned legislation.

The identification of legislation as 'most important factor' for growth amongst questionnaire respondents is further questioned since respondents may have neglected that there is no direct link between the industry sector's activities and the contribution to environmental legislation. As outlined above there is no documentation or procedure to record and credit the contributions made by automotive remanufacturing.

Concluding, product take-back and recovery legislation, such as the ELV Directive, could not be confirmed as a reason for OEM automotive remanufacturing, for the specific case companies and the product groups under investigation. However, it could be a motive for remanufacturing within other industry sectors or for other product groups. Future research also needs to further investigate this finding for the independent automotive remanufacturing sector.

10.2.3 The Direct Economic Motive (Profitability of Remanufacturing)

The last question, Research question 5, asked whether a direct economic motive (profitability of remanufacturing) has been a reason for industry players to engage in automotive remanufacturing: Is automotive remanufacturing induced by direct economic motives (i.e. profitability of remanufacturing)? As already outlined at the end of Section 3.4.2, this research question refers to the direct profitability of the remanufacturing operation (note: direct profitability as defined in Section 3.4.2). The following section therefore examines the results of interviewees with regard to a direct link between the remanufacturing operations, the sales of the products and the positive (financial) results of those sales as a motive for the case companies to undertake remanufacturing.

Research on closed-loop supply chains within operations management research has tended to assume that the profitability of product recovery has been sufficiently explored. In fact, this is not the case, as Guide *et al.* (2003b) argue:

> *The focus on operational issues presupposes that the basic question of profitability has been adequately addressed, or is obvious. Our experience with global firms engaged in electronics, telecommunications, and power tools suggest the question of how to make reuse activities profitable has not been adequately addressed.*
>
> (Guide *et al.*, 2003b, p.5)

This section seeks to demonstrate the role of profitability within the automotive remanufacturing sector. Hereby, the perspective of the original manufacturer is taken. Johannes (1995) has compared the prime costs between engine remanufacturing and the production of new engines (see Figure 33).

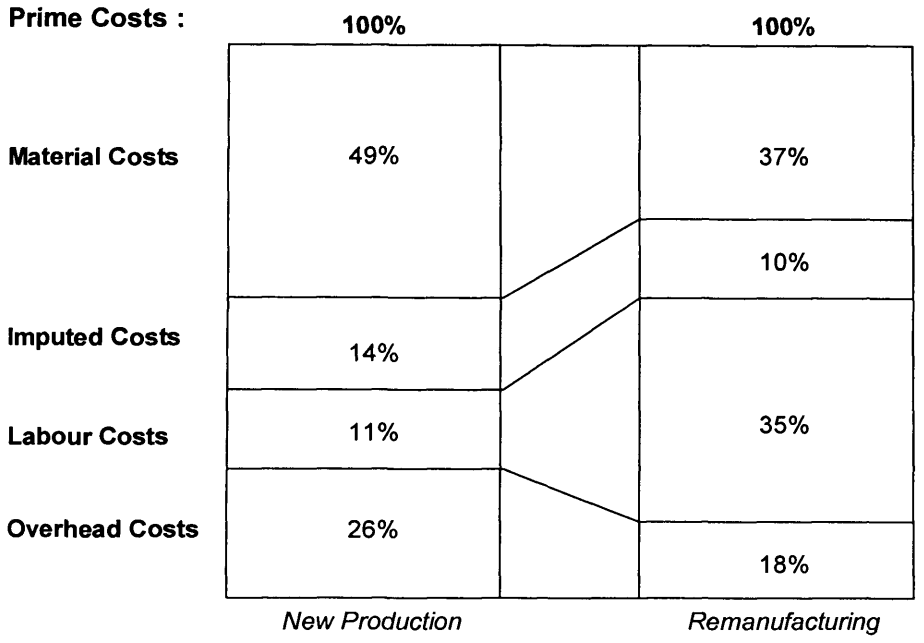


Figure 33: Prime Costs of New Engine Manufacturing versus Engine Remanufacturing (Source: reproduced from Johannes, 1995, p.24; translated from German)[92]

As the figure shows, remanufacturing may benefit from lower material costs compared to new engine manufacturing, assuming that the used products (cores) are less costly than new parts. However, there are further considerations. On the one hand, cores may indeed be less expensive than new parts. On the other hand, their acquisition incorporates high uncertainties. The discussion on scrap rates in Chapter Six has demonstrated that there are high risks involved within core acquisition as a source for 'raw material'. Moreover, it may be assumed that within OEM remanufacturing, the 'true' condition of the core is only discovered in the dismantling process as the results of Case One (Company A) have shown. Retailers may assess the core according to its damage and a reduced rebate may be accredited, as Chapter Six has briefly noted. However, it may be assumed that due to a separation of the core acquisition and the dismantling process, further damages may only become aware within the remanufacturing plant. As a result, the retailer may have paid an inflated rebate.

[92] In this graph, imputed costs include the depreciation and amortisation of fixed assets, whereas overhead costs comprise costs such as machine maintenance, tools and commodities (e.g. machine lubricants).

Due to a take-back network structure that stretches across several supply chain echelons and the time delays in the return process, the OEM engine remanufacturer therefore takes a higher financial risk within core acquisition than a smaller independent player, for example. A good case in point is the high stock level of 13,000 cores which were stored at the remanufacturing plant. For some engines it may take months until they are assessed with regard to their quality and re-usability in the disassembly process. The quality manager and person in charge for Company A's return processes (located at the Global Warehouse) was asked whether it may be argued that there is no interface between the core quality assessment at the retail level and the refund of the rebate. He replied:

> *According to my knowledge, the rebate is a result of a mixed calculation (we are aware that not every engine can be remanufactured in the same way and with the same financial expenditure). Moreover, the rebate is market-oriented (i.e. it has to be adjusted in a way that we receive the cores and that these are not sold to another remanufacturer for a higher price – with engines this does not seem to be the case). As you have rightly noted, there is no direct link between the quality assessment and the refund of the rebate. At the time of the core analysis, the remanufactured engine has long been delivered to the customer and the vehicle is back on the road. The only reduction of the rebate which exists is the discount of the rebate in the case of missing or defective parts, as you have mentioned in your enquiry.*[93]

A second interviewee, a marketing and sales manager at the company's Headquarters claimed that this is the most economical solution for the company. He hereby also refers to accounting issues incorporated within product take-back and recovery.

> *The quality of returned cores is logically subject to strong variations, ranging from practically unusable to nearly undamaged. Since a complex quality assessment would be too costly with regard to the vast amount of cores and may also not demonstrate the necessary accuracy, a flat valuation is permitted and has been arranged with financial auditors but is also allowed by law.*[94]

[93] Quoted from personal communication (E-Mail) with the Manager for Reverse Logistics, Quality and Process Management at Case Company A's Global Warehouse, January 2004, translated from German.
[94] Quoted from personal communication (E-Mail) with the Manager for Marketing and Sales at Case Company A's Headquarters, October 2003, translated from German.

The second argument which questions profitability of OEM remanufacturing is the competition for cores. As this research has found, there is fierce competition for used engines. One may assume that competition also leads to an increase of core prices. Several interviewees have stated that the OEM remanufacturer aimed at 'cleaning the market' so that independents do not have access to cores. In addition, the questionnaire survey has confirmed that independent remanufacturers, indeed, felt the results of this strategy. Nineteen respondents (45.23%) perceived the non-availability of cores as the 'most important factor' which restricts growth. In order to protect their brand image from remanufacturing activities performed by the independents, the OEM buys back any core. One independent remanufacturer stated:

> *At the MAN AG, commercial vehicle engine cores are scrapped under supervision. This is just another example of how OEMs want to exclude independent remanufacturers from the market.*[95]

The author therefore assumes that OEM remanufacturers are, compared to independent remanufacturers, less profitable with regard to core acquisition, due to the fact that one of their main motives is the exclusion of independents from the remanufacturing market. This also implies that OEMs need to pay higher prices for cores than other players in the market and that they will buy back any core. These factors have an impact on the profitability of OEM remanufacturing operations.

Overall, interview results demonstrated that there seemed to be a difference between interviewees stemming from the independent sector or with strong links to the independent side of the sector and interviewees taking and OEM perspective. The general consensus was the fact that remanufacturing operations performed by independents were more likely to be profitable and/or driven by the motive of profitability than operations undertaken by the Original Equipment Manufacturers. With regard to independent remanufacturing, interviewees stated the following.

[95] Quoted from the interview with the Managing Director of an independent engine remanufacturer, Case Eight, December 2003, translated from German.

> *The remanufacturing of valuable used parts is not particularly a result of environmental considerations, but primarily undertaken because there is a lucrative market.*[96]

> *Remanufacturing ought to be profitable, otherwise, why would they do it? On the other hand, even engine manufacturing has very small profit margins with only 2% return on revenue, that's nothing.*[97]

However, other interviewees contradict, particularly respondents within OEM facilities.

> *Remanufacturing of car engines is not profitable enough. The motivation for remanufacturing is purely based on image with regard to several aspects, quality of recovery and representativeness in the market, for example.*[98]

> *We hardly make any profit with remanufactured engines. But why are we so interested in remanufacturing then? Well, the reason is that we want to be quick. In some cases a remanufactured engine is the only possibility to provide a replacement in a short timeframe.*[99]

In addition, there is the need for a distinction between different automotive parts with regard to the role of a direct economic motive. One interviewee confirms that the remanufacturing of steering racks and arms has been unprofitable for the Vehicle Manufacturer A and therefore the company ceased to offer remanufactured steering parts. However, the question arises whether a vehicle manufacturer could stop to provide remanufactured car engines should these be unprofitable. A second interviewee confirms:

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[96] Quoted from personal communication (E-Mail) with Thomas Kobudzinski from Department for Public Relations at the Gesamtverband Autoteile-Handel e.V. (German representation of interests – independent parts distributors) in Ratingen, Germany, October 2003, translated from German.

[97] Quoted from the telephone interview with Edward J. Hadingham, the Managing Director European Operations of Power Systems Research in Brussels, Belgium, September 2003. See full interview in Appendix G, Key Interview 2.

[98] Quoted from the interview with the Manager Sales for remanufactured engines at Case Company A's Remanufacturing Plant, June 2002, translated from German.

[99] Quoted from the interview with the Manager for Customer Process Management at Case Company A's Global Warehouse, September 2002, translated from German.

Sometimes, a remanufactured engine only makes a contribution to the overall costs, such as warehousing or logistics, that's it. But this is also a reason why we remanufacture.[100]

When we firstly introduce a remanufactured product to the market, the overall contribution to fixed costs instantly plummets. This is due to the fact that remanufactured parts have significantly lower profit margins than new products. With regard to current sales figures, the exchange business cannot be perceived as profitable. Remanufacturing definitely is a long-term strategy.[101]

Thirdly, as outlined in Chapter Six, remanufacturers depend on new parts, such as pistons, bearing shells or gaskets. Depending on the age of the engine, some of these parts have to be hand-made or produced in low volumes and are therefore higher priced than mass manufactured engine parts. The conclusion that engine remanufacturing is, with regard to material costs, more economical than the manufacturing of a new engine (as outlined in Figure 33), may therefore be misleading.[102] In fact, the prices for these new parts are unpredictable and may increase the overall price for a remanufactured engine significantly. The research has also shown that small, independent outlets often manufacture their own new parts, such as gaskets. It has also been outlined in Chapter Two that many independents aim at 'saving a part', which may often incorporate activities that are classified as repair processes (such as the welding of parts) rather than a remanufacturing operation in a strict sense. The OEM, on the other hand, may be rather reluctant to follow this route, since the aim is to achieve an 'as good as new' standard. As a result, the OEM remanufacturer does significantly depend on new parts which are necessary to maintain the reputation of the 'as good as new' standard, whereas the independent remanufacturer may be more flexible in this respect.

[100] Quoted from the interview with the Product Manager Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, September 2002, translated from German.
[101] Quoted from the interview with the Product Manager for Remanufactured Parts at Case Company A's Headquarters, February 2003, translated from German.
[102] The assumption by Johannes (1995) can particularly not be confirmed if manufacturing and remanufacturing operations overlap. As long as an engine is manufactured in high volumes, it is very likely that the new engine is produced at less cost. See also Tables 45 and 46 in Section 6.5.

Johannes (1995) furthermore explains that due to the large amount of manual processes involved in engine remanufacturing, labour costs are by far larger than within the manufacturing of new engines. They even may be three times higher than labour costs in high-volume engine production. In fact, labour costs in Western Europe, but particularly in Germany, are high. In addition, the comparatively low level of automation within remanufacturing has been pointed out throughout this thesis. It results in an increasing requirement for manual labour, since fewer processes can be undertaken by machinery. As already pointed out by Steinhilper (1998), results from experiments showed that robots and machines may be used in certain remanufacturing processes and even within engine remanufacturing. However this machinery requires large batch sizes in production in order to be economically viable. This dissertation has demonstrated that within engine remanufacturing operations, large batch sizes tend not to occur. Steinhilper (1998) argues that the use of high-maintenance equipment and machinery in the disassembly process, for example, leads to costly efforts and downtimes in the process, due to the resetting of tools, jigs and fixtures. He therefore concludes that "in practice, therefore, manual or moderately mechanized disassembly will remain the adequate solution for the future" (Steinhilper, 1998, p.45-46). Johannes (1995) furthermore adds that there is a lack of necessary methods and instruments to mechanise the remanufacturing process. Chapter Six has also shown high throughput times for the individual remanufacturing process steps. It therefore seems as if remanufacturing will remain an operation with low automation, high manual labour, high skill requirements as well as high throughput times. These factors may lead to increasing labour costs and may also result in a decreased competitiveness of products that are remanufactured by the OEM.

The above discussion on material and labour costs has demonstrated the limits with regard to the profitability of OEM engine remanufacturing. However, during the research, the author has faced several obstacles in seeking an answer to this question. First of all, Company A's financial data was spread over the whole closed-loop supply chain, a phenomena which is well-known to product recovery operations research, as Thierry *et al.* (1995) confirm "[...] many manufacturers did not consider PRM to be a (core) business activity. Required data are often scattered throughout the company or business chain, or are not available at all" (p.132). Within Case Company A, the

controlling department at the remanufacturing plant calculated the internal prices for remanufactured engines. There were two internal prices. The first comprised production costs (prime costs for the remanufacturing plant); the second represented the sales price to the Global Warehouse. Employees in the Headquarters further amended these prices in order to calculate the price for the retailer. However, there was no employee or department with a complete overview of prices or calculations. Moreover, access to financial data was limited due to confidentiality.

Overall, none of the interviewees in Case Company A could report or provide the author with a sound profitability analysis for car engines, for example. However, interviewees referred to further predominating reasons for engine remanufacturing. The situation for electronic devices will be outlined later in this chapter. With regard to OEM engine remanufacturing, however, the author therefore assumed that a corporation, which is entirely unaware of a particular operation's profitability, must have further, predominating motives to undertake the activity. In addition, a corporation that is driven by profitability would also seek to overcome main issues and obstacles and consider all relevant aspects in order to measure and increase its profitability. In the case of Company A, this would have meant the identification of all cost factors (including costs for reverse logistics) or the increase in efficiency with regard to the process, but also core acquisition, for example. This also indicates that the direct economic motive (profitability of remanufacturing) must be seen as a minor role for the establishment and undertaking of remanufacturing within the companies that were investigated.

It may be assumed that these findings are also valid for electronic device remanufacturing, as the Manager for Technical Documentation and Customer Support at Company C explains:

> *We are providing a service for the VM. We therefore don't consider any financial limits within remanufacturing. Our limitations are of a technical rather than a financial nature. Every device will be remanufactured, no matter how severe the damages or replacements are. In exceptional cases, for example if there is a series of severely damaged products, we get in touch with our client and the client may fully cover the exceptional costs.*[103]

However, due to the fact that OEMs have only been interested in electronic device remanufacturing from the late 1990s onwards, there even seemed to be less awareness with regard to profitability of the remanufacturing operation than there was for engines. Company B therefore established a project with the aim to understand, manage and control electronic device remanufacturing.

> *At the moment, our motivations for electronic device remanufacturing are based on two reasons. Firstly, because of customer loyalty. Secondly, we make cost savings with regard to warranty. We don't even know if electronic device remanufacturing pays off, since, to date, profitability or other financial aspects of remanufacturing have been left completely unconsidered. From a more practical point of view, the decision-making process has been based on the technical feasibility and on the fact whether the price of the new product is more than 100 Euros. Those two factors had been chosen absolutely arbitrary. In the new project, we have to redefine these and base them on a sound analysis of all aspects of remanufacturing. It may also be worth considering marketing aspects, for example whether the supplier also remanufactures this specific product.*[104]

The Team Leader of Stock and Supplier Management for Electronics at Case Company B adds:

> *There are two main tasks in this project. Firstly, we have to calculate the remanufacturing process costs of individual variants. Process costs include, purchasing price from the supplier, warehousing, reverse logistics and administration. Secondly, we need to calculate the profitability of individual product variants, because we need to compare the different strategies of aftermarket supply, for example redesign, repair, remanufacturing or all-time buy.*[105]

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[103] Quoted from the interview with the Manager for Technical Documentation and Customer Support at Case Company C, March 2003, translated from German.
[104] Quoted from the interview with the Manager Stock and Supplier Management for Electronic Devices at Case Company B, February 2003, translated from German.
[105] Quoted from the interview with the Team Leader of Stock and Supplier Management for Electronic Devices at Case Company B, February 2003, translated from German.

The Vice President for the Market Segment Original Equipment Supplier of Company D, one of Company B's suppliers, confirms that their clients' (the VMs) expectations are always too high with regard to the profitability of remanufacturing.

> *The Vehicle Manufacturers always expect profitability from remanufacturing, but that's unrealistic. Fact is that there is a lot of waste of money, particularly with regard to reverse logistics.*[106]

More generally, it has been outlined at several places that for a vehicle manufacturer, remanufacturing is a non-core activity. Case Company A has outsourced a large amount of this operation after the research had been conducted. It may therefore be concluded that profitability of this operation was not one of the company's driving forces. Instead, interviewees explained that engine remanufacturing was perceived as a 'necessity' in order to exclude competition and to provide the supply of replacements, for example. More critically, the remanufacturing sector is a sector that offers alternatives to new replacements. OEMs are rather interested in the distribution of new goods, but have felt the pressure to be active in a sector that seeks to replace their premium replacement goods with cheaper alternatives.

> *At present, engine re-manufacturing is not a growth industry as the standard of engines today is far superior to those some thirty years ago. The growth in general automotive re-manufacturing is mainly due to the high cost of OE parts. This has led people to look at other options. Second hand parts were always the second option, but were fraught with problems. People found that they wanted a better quality, but not at OE prices. It is my view that re-manufacturing was basically born from this concept. Engines have always been rebuilt, but never brakes, turbochargers etc., and this is where the main development of the industry has been.*[107]

[106] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at Case Company D, July 2003, translated from German.
[107] Quoted from personal communication with Brian Ludford, the General Secretary of the UK Division of the Federation for Engine Re-Manufacturers (FIRM), Plymouth, June 2004. See full interview in Appendix G, Key Interview 6.

Moreover, if Company A sold a remanufactured engine for a 'loss', as demonstrated in Chapter Six (as outlined in Section 6.5), it did not necessarily indicate an overall loss for the remanufacturer. According to Wöhe and Döring (1996), products generating losses may still make a contribution to overall fixed costs and are therefore still essential to the product range. Figure 34 shows the profitability life cycle for an aftermarket strategy including remanufacturing. The dotted line demonstrates the development of profitability including remanufactured products. At Company A, profit margins were smaller for remanufactured products than they were for new replacements. However, Company A claimed that through the extension of the product range by remanufactured parts, the company's aftermarket position was improved. Figure 34 furthermore shows an overall increased profit, compared to a strategy without remanufactured parts. This may explain why Company A did not pay much attention to identifying whether the sales of remanufactured products from specific product groups resulted in a profit, but rather saw those products as a part of an overall aftermarket strategy.

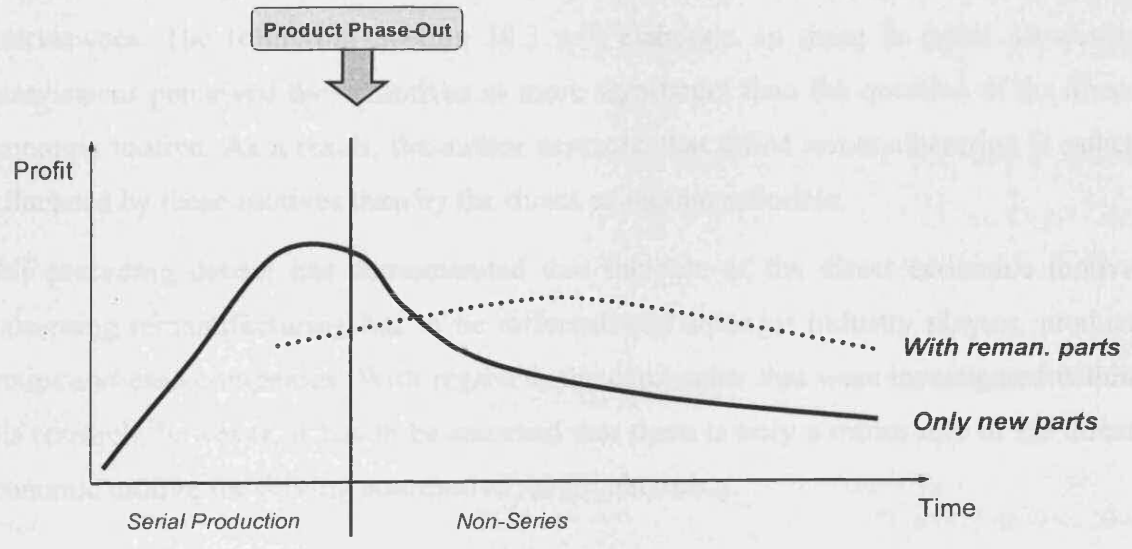


Figure 34: Profitability Life Cycle of New and Remanufactured Parts (Source: reproduced from Case Company A)

This section has discussed the direct economic motive as a reason for automotive remanufacturing. Several findings were made. Firstly, a distinction needs to be made

between the independent remanufacturing sector and the motivations for OEM remanufacturers. It is very likely that independent remanufacturing is profitable and therefore the direct economic motive plays a major role. However, this research has focused on the Original Equipment Manufacturers undertaking remanufacturing. These include vehicle manufacturers and suppliers of original equipment. With regard to the companies that were investigated, there was a lack of knowledge whether a specific operation was profitable or not. Analysing the profitability of remanufacturing not only seemed challenging, given the vast amount of aspects to consider, but also not practiced on a regular basis. The author therefore assumed that companies that are not aware of the economics of a specific operation cannot be driven by a direct economic motive. Otherwise, the remanufacturers would be interested in measuring and improving the performance. Secondly, a variety of factors have been discovered in the course of interviews that have an influence on the profitability of OEM automotive remanufacturing, such as the strong competition for cores, expensive new parts added to the process as well as high labour costs. It therefore seemed that independent remanufacturers have an advantage with regard to these aspects. Thirdly, a variety of new, predominating reasons for the rationale behind remanufacturing were expressed by interviewees. The following Section 10.3 will elaborate on these in detail. However, interviewees perceived these motives as more significant than the question of the direct economic motive. As a result, the author assumed that OEM remanufacturing is rather influenced by these motives than by the direct economic rationale.

This preceding debate has demonstrated that the role of the direct economic motive concerning remanufacturing has to be differentiated amongst industry players, product groups and case companies. With regard to the companies that were investigated within this research, however, it has to be assumed that there is only a minor role of the direct economic motive for driving automotive remanufacturing.

10.3 Reasons for Remanufacturing – New Research Findings

The first part of this Chapter has investigated three motives for product take-back and recovery and for remanufacturing in particular. These motives included ethical and moral responsibility, environmental legislation as well as the direct economic motive. These three reasons had been taken from the literature (Chapters Two and Three) and examined with regard to their applicability to the OEM automotive remanufacturing sector. This section, however, discusses newly identified motives that were perceived as predominating over all other motives by interviewees.

10.3.1 Information Feedback

Lund (1984b) has outlined the benefits of information feedback from the (technical) discoveries made within remanufacturing to future product design. This thesis has also discussed the significance of 'design for environment' or 'design for remanufacturing' measures within the design phase of OEM products. However, despite the fact that vehicle manufacturers are aware of ELV regulations, the interview with the person in charge for 'design for recycling' at BMW (see Chapter Three) has revealed two major issues. On the one hand, the increasing amount of plastics in cars is a major obstacle to meeting the targets which are set by EU law. On the other hand, high-end luxury cars, if they return as 'natural ELVs', are more difficult to recover than other cars, due to the additional amount of convenient features, such as sound insulation. These examples show that VMs are aware of the relevance of environmentally friendly design; however they seem not to consider it in all of their products.

This dissertation has demonstrated that in the case of passenger car engines, the situation is not different. Firstly, there are new engines being produced, which cannot be remanufactured. A good case in point is the engine from the MCC smart car. Interviewees claimed that this engine is not remanufacturable.[108] Moreover, this engine is produced at low cost. Hence the new engine is relatively inexpensive. As it has been

[108] More recently, one independent remanufacturer, MRT Engines B.V. (The Netherlands), claims to remanufacture those engines. See also Schwarck (2004).

outlined in Chapters Six and Seven, the price of the new product is a strong determinant in the decision-making process of the establishment of an exchange cycle. In the case of engines which can be produced at low cost, there is no intention to setting up a remanufacturing cycle.

Secondly, interviews revealed that there is no communication between engineers located at remanufacturing plants and designers and engineers of new products. Although Case Companies A and B seemed to be aware of the issue, designers were not willing to co-operate with aftermarket experts:

> *When we raise the problem, developers tell us "we develop for the series, not for the aftermarket."*[109]

> *The main issue here is that product development wants differentiation and the aftermarket management wants standardisation. However, there is no link between the two parties.*[110]

> *Serial thinking and aftermarket thinking is so distinct that assembly lines for new electronic devices and remanufacturing work spaces have to be separate and cannot be combined into one assembly line in any way.*[111]

The same is true for electronic suppliers who aimed at incorporating 'design for environment' measures into their products. However, the section on product remanufacturability in Chapter Five has demonstrated that despite this awareness, the supplier depends on the customer (the VM) who may decide, due to financial limitations of the design budget, not to incorporate these features into the product:

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[109] Quoted from the interview with Manager Technical Support for Chassis at Case Company A, September 2003, translated from German.
[110] Quoted from the interview with the Product Manager Service and Parts (Car Life Cycle Management) at Company A's Headquarters, September 2002, translated from German.
[111] Quoted from the interview with the Shop Floor Manager for Remanufacturing at one of Case Company D's remanufacturing plants, July 2003, translated from German.

> *'Design for recycling' is included in all our contracts with vehicle manufacturers, but no one cares about it. If we tell a vehicle manufacturer's buying agent that an eco-designed connexion with screws is two cents more expensive than the conventional connexion, the buyer thinks to himself: I'll ignore that, in three years time I won't be in this job position any more.*[112]

To summarise, these examples have shown that the industry is aware of a potential (environmental) information feedback from remanufacturing to new product design. However, current industry practice differs from what the literature suggests.

There are various other forms of information feedback from remanufacturing. Academic literature has often investigated feedback to future (OE) product designs. As this research has shown, this may be difficult to implement in large corporations. There are two additional forms of information feedback which have been revealed within this dissertation. The electronics case study has shown that there is information feedback from remanufacturing to the current assembly line (see in-plant manufacturing errors, field returns and zero-mile returns; Section 7.5). This information feedback could be described as a way of eliminating product defects within the current production. Hence, it refers to a direct feedback from the remanufacturing (dismantling) facility to the current production (assembly line). It seems as this type of feedback is valid and significant for products with shorter life cycles than engines. As Chapter Six (Figures 18 to 21) has pointed out, the remanufacturing of engines usually commences several years after the engine's introduction to the market and experiences strong demand after one or two years of serial production. In the case of engines, it seems that the original manufacturing process has already, at that point in time, improved the product through the creation of new engine variants. It can therefore be concluded that the benefits of information feedback are applicable to products for which the time-span between OE production and return for remanufacturing is short. The case study on electronics remanufacturing has been a good case in point to demonstrate this aspect.

[112] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at Case Company D, July 2003, translated from German.

The second type of information gained from electronic device remanufacturing is the accurate determination of the cause for product failure cause and the quantity of faulty products. Even though Case Company B claimed that the detection of frequent production errors provided valuable feedback for the research and development department, one of the predominant reasons for product take-back, examination and recovery seemed to be the identification of the supplier's failure rate. By identifying the 'quota' or 'rate of recourse', the vehicle manufacturer calculated the amount of defective parts to charge the supplier.

As a result, information feedback from remanufacturing was found valuable for the current manufacturing process and the identification of failure rates. However, this could only be confirmed for electronic device remanufacturing and not for car engine remanufacturing. The author assumes that the shorter life cycle of electronic devices gives more scope for the application of such information. Compared to that, within engine remanufacturing, the remanufacturing life cycle begins significantly later than the original production.

10.3.2 Aftermarket Reasons: Securing Spare Parts Supply and Warranty

The first truly new reason for remanufacturing which has emerged from this research can be termed as the 'securing of spare parts supply'. This section discusses the importance of this reason for engine and electronic device remanufacturing.

As outlined in Chapter Five and Seven, one of the main obstacles in providing replacement parts after the phase-out of the serial production is the increasing dependency on the suppliers. In many cases, tools and machinery are broken down when the equipment for the new car model takes up its place on the production floors. For spare parts, this usually means sharp price increases. Company B's Global Warehouse has reported price increases between 200% and 300% (compared to serial production). One interviewee at supplier D, on the other hand, defended this position by claiming that vehicle manufacturers should not expect to procure parts at serial conditions two years after the termination of production. As a result, remanufacturing

reduces the dependency on suppliers after the termination of production in terms of prices and parts availability. Two interviewees confirm:

> *Cores are so important and valuable for us because they are not mass-produced any longer. They are also cheaper than parts that are specifically manufactured by the supplier* [often in small volumes]. *Cores are therefore the only source of parts for which there is no serial production any more.*[113]

> *The vehicle manufacturers always tell us suppliers: you have to do this; you have to do that and so on. And the most ridiculous claim is that three years after serial production they still want the parts at serial conditions (price).*[114]

The secure supply of spare parts is particularly important for the automotive sector, in which many vehicle manufacturers guarantee to cover for a period of 10 years or more. In some cases, remanufacturing is the vehicle manufacturer's only option to provide spare parts.[115] Interviewees have confirmed that remanufacturing is a significant source of replacement engines. This aspect is particularly relevant in the classic car sector. The installation of remanufactured parts in cars may therefore be seen as the extension of the car's product life cycle. This product life cycle extension, however, is not based on environmental motives, but rather a result of the car owner's interest to extend the vehicle's life:

> *With remanufactured products we complement our aftermarket programme of repair (dealers and subsidiaries) as well as used parts (Used Parts Centre). We want to offer the customer a choice.*[116]

> *Our company makes no profit with the classic phase of a car model, even though our market share of classic cars is 50% in Germany. But it's all about the image.*[117]

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[113] Quoted from the interview with the Manager for Customer Process Management at Case Company A's Global Warehouse, September 2002, translated from German.
[114] Quoted from the interview with the Vice President for the Market Segment Original Equipment Supplier at Case Company D, July 2003, translated from German.
[115] These cases include the bankruptcy of a supplier or supply of a product with a very long life cycle, for example.
[116] Quoted from the interview with Manager Technical Support for Chassis at Case Company A, September 2003, translated from German.
[117] Quoted from the interview with the Team Leader for Stock and Supplier Management for Aggregates at Case Company A's Global Warehouse, September 2002, translated from German.

The literature also confirms:

> *Others are reusable after reconditioning: alternators, air conditioners, even entire engines. This is particularly important where the engines and components are no longer being manufactured, so recovered and reconditioned parts are the only effective way of keeping older vehicles in service.*
>
> (Graedel and Allenby, 1998, p.148)

The remanufacturing of car engines is therefore a necessary operation to maintain the company's ability to provide replacements for customers. Chapter Seven has outlined that there are several strategies to secure the supply of electronic spare parts, for example by redesigning and reproducing the device. However, in the engine segment, a reproduction is very unlikely since the engine is a complex product of over 500 parts. For all the parts that are manufactured through casting and machining processes (e.g. cylinder head, cylinder block, connecting-rods, camshaft, crankshaft), it is very unlikely that these are being reproduced in small volumes. It may therefore be concluded that for mechanical parts and components, remanufacturing is an essential source to secure spare parts supply.

A second important aspect of spare parts management is the allocation of under-warranty engines. The average warranty for new cars is three years or 60,000 miles (Lewis, A, 2003). In fact, the car owner does only receive a brand-new engine if the product failure occurs within the first 10,000 to 15,000km, on average. For every under-warranty case above this mileage, the car owner receives a remanufactured engine.

> *Today, engine remanufacturing is a vibrant and growing industry. As powertrain warranties continue to increase, most automakers want to find suppliers to carry them through the warranty period. People are keeping their cars longer, and replacing their engine is a cost effective alternative to replacing the vehicle.*
>
> (Marshall Engines, 2003)

This research has not particularly investigated the amount of 'warranty engines' within Case Company A. However, exact figures are difficult to obtain, also for industrial players, such as this subcontracted remanufacturer confirmed:

> *Our remanufactured engines are designed (in the remanufacturing specifications) to be as good as new, which means they can serve as warranty replacements. However, we do not receive any information which will allow to determine the split between warranty replacement and aftermarket purchase. The majority of our engines are from vehicles outside the normal warranty period, but of course many consumers buy extended warranty terms from the dealer.*[118]

By cultivating a reliable 'pool' of warranty replacements, the vehicle manufacturer decreases its warranty costs by providing the customer with a recovered product instead of a brand-new engine:

> *There are four main reasons why we provide remanufactured products. Number one: because the market wants it. Number two: high number of warranty cases. Number three: it is part of product phase-out management. Number four: cores have to be taken back because we don't want competitors to get hold of them.*[119]

> *Important is the overall view and the consideration of all engines, as discussed in the interview: warranty – which we pay anyway - and the ability to supply across the whole car life cycle.*[120]

> *The main reason for Company D to remanufacture is to decrease warranty costs.*[121]

Moreover, remanufacturing is likewise a measure to balance aftermarket engine demand and the demand for new engines in the vehicle assembly process. Since the manufacturing output of new engines is related to the vehicle assembly operation, the withdrawal of new engines from the serial production would lead to an engine shortage

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[118] Quoted from personal communication with Tim Durdin, the Managing Director of Wealdstone Engineering Ltd. in Rushden, UK, January 2004. See full interview in Appendix G, Key Interview 4.
[119] Quoted from the interview with the Product Manager Remanufactured Parts at Case Company A's Headquarters, February 2003, translated from German
[120] Quoted from personal communication (E-Mail) with the Product Manager Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, October 2004, translated from German. See full interview in Appendix G, Key Interview 1.
[121] Quoted from the interview with the Shop Floor Manager for Remanufacturing at one of Case Company D's remanufacturing plants, July 2003, translated from German.

in the vehicle assembly process. Hence remanufactured engines may fulfil the demand for engine replacements.

This research has also demonstrated the important role remanufacturing plays in the electronic device segment. The termination of a part produced by a semiconductor manufacturer has been identified as a critical factor to automotive spare parts supply. According to Company B's records, a discontinuation of delivery from the parts supplier's side occurs if complete production lines are closed down, if there is a change in technology, or in the case of modifications in the production process. Semiconductor producers and distributors argue that in most cases (90%), another part can replace the discontinued part (based on information by Company B).

In case of a discontinuation of delivery, however, the vehicle manufacturer and the supplier have limited powers. Chapter Seven has demonstrated that remanufacturing of electronic components may therefore be seen as one of a very few options to supply the aftermarket with products at a price, which is justified to the residual value of the car. According to Company B's team manager, the main reason for offering this long-time supply of spare parts is the strengthening of customer loyalty. The manager further explained that by buying a car of this particular vehicle manufacturer's luxury brand the customer pays a premium price. However, the price for this upper-end car includes additional services, such as an extensive range of spare parts. Another interviewee further outlined:

> *Five years after a car model's phase-out, our medium-priced competitor X, offers a certain spare part (e.g. exterior mirrors) in just one or two colours. We* [Case Company A], *on the other hand, provide all colours. That makes a difference, also to our inventory management. Moreover, some of our competitor's parts may only be available as complete component. If a customer requests an electric bulb for the front light, he might have to purchase a whole new headlamp.*[122]

[122] Quoted from the interview with the Team Manager for Service and Parts (Car Life Cycle Management) at Case Company A's Headquarters, September 2002, translated from German.

Chapter Seven has shown that, from the vehicle manufacturer's point of view, one of the main reasons for electronic device remanufacturing was an increase in warranty claims. In the 1990s, under-warranty parts were removed by retailers and scrapped without exception. However, the vehicle manufacturer became aware that by scrapping these, not just a valuable automotive part was lost, but also recycling costs had to be paid. Electronic devices are relatively valuable, taking the example of a navigation system or an autopilot system, which are sold between €1,000 and €3,000.[123] Chapter Seven has discussed the large amount of NFF products. In other words, a large amount of devices which had been removed in the late 1990s and early 2000s had been in good working order. According to Company B's electronics team leader, the retail level was to blame for the increase in NFF removals.

> *Car users don't have a clue about how to use the devices, such as autopilot and navigation systems. But do you think a retailer can tell the owner of a 150,000€ car that he has pressed the wrong buttons? Rather than embarrassing the customer, retailers just install a new device.*[124]

Remanufacturing of electronic devices has served two objectives. First of all, the vehicle manufacturer was able to deal with a growing 'mountain' of expensive, shortly used, but perfectly working electronic devices (NFF parts). Moreover, the remanufactured products have represented replacement parts to serve the aftermarket. Since NFF products may have been restored to an 'as good as new' condition with few process steps, such as the upgrade of the software, remanufacturing costs of these products were kept at a minimum. For other suppliers, such as Case Company C, the reduction of warranty costs was the main motive to undertake remanufacturing. Supplier C has explained that between 50 and 70 percent of the devices being returned for inspection could be identified with supplier faults (SF). Hence, the supplier had a great interest in using the cores in a sensible way, since compensations for these were made to the vehicle manufacturer. For a successful establishment of a remanufacturing cycle, however, the supplier will always need the vehicle manufacturer's support.

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[123] Purchasing price between €150 and €1,000 from the supplier.
[124] Quoted from the interview with the Team Leader for Stock and Supplier Management Electronics at Case Company B's Global Warehouse, February 2003, translated from German.

> *We always try to persuade the vehicle manufacturer of the benefits that the exchange cycle incorporates. Vehicle manufacturers often agree to the establishment of a remanufacturing operation, since there is a large amount of NFF products returning from the field, for which the supplier cannot be made responsible. In other words, both parties benefit from remanufacturing. We tell the vehicle manufacturer, if you don't agree to the establishment of an exchange cycle, we won't agree to the 'spare parts circus.' Since, after a while, some of the devices may not be available any more, they agree to the establishment of a remanufacturing cycle.*[125]

From a technical perspective, electronic device remanufacturing has also been an opportunity to benefit from the extensive warranty adjustment process. Chapter Seven has shown that the remanufacturing of an electronic device only requires a few more steps to the product failure identification within the warranty adjustment process. The remanufacturing cycle set-up costs were therefore relatively low. Hence, one further reason for the suppliers to remanufacture the devices was the relatively low additional cost.

10.3.3 Market Share and Brand Protection

Lund (1984b) has confirmed that remanufacturing may be a defensive action by OEMs to discourage competitors from the remanufacturing of OEM products. The research has shown that there are two dimensions of a defensive action undertaken by OEMs. The reasons 'brand protection' and 'market share protection' have been identified as outcomes of this research and may be considered as novel findings. Previous research has not elaborated on these specific motives for remanufacturing, but rather briefly noted the existence of 'market protection' as a 'driving-force' for remanufacturing (e.g. De Brito *et al.*, 2003a).

[125] Quoted from the interview with the Manager for IT Integration at Case Company D, July 2003, translated from German.

Within Case Company A, aftermarket share and brand protection have been identified as a decisive reasons for the establishment of a remanufacturing cycle. This may be due to the fact that in the automotive sector, brand management and awareness have always been key components to success (e.g. Plume, 2000). As a result, market research companies and consultancies are aiming at the understanding of consumer and brand values within strategic brand management. The Roland Berger Market Research company, for example, differentiates between 'rational' and 'emotional' values, of which brands consist (Roland Berger Market Research, no date given).

With regard to brand awareness and protection, this research has discovered that Case Company A did not wish that any other remanufacturer 'plays around' with the engines. As a matter of fact, there was the fear that customers may not distinguish between the brand name on the engine and the potential low-quality recovery undertaken by independents. In order to protect the company's luxury brand, the OEM sought to ensure that remanufacturing only took place in the vehicle manufacturer's plant. This gave the Case Company the control over the quality of remanufactured products and sought to ensure that the product performance met the customer's expectations. The case company based these claims on the argument that for remanufacturing engines, sophisticated equipment is required.[126]

Moreover, interviewees at Company A's plant over-emphasised the fact that highly skilled labour is an essential part of remanufacturing in order to ensure that quality levels can be met. The Case Company A assumed that if a considerable amount of their luxury car engines would be remanufactured by the independent sector, it would reflect negatively on the company's image. However, the arguments raised by Vehicle Manufacturer A have to be seen in perspective. In fact, there is no evidence that engines, which are being remanufactured by highly skilled workers in the vehicle manufacturer's original plant, are qualitatively superior to engines remanufactured by independents.

[126] It can be confirmed that independent outlets tend to have a smaller stock of machinery as the visit to a small independent German remanufacturer has shown, but this does not necessarily indicate and inferior quality of the remanufactured product.

It may be assumed that vehicle manufacturers have used this argument in order to build a 'quality image' for the product group 'remanufactured' which may have been perceived as inferior to new OE replacements. Furthermore, their argumentation may seek to justify a potentially higher price for remanufactured engines compared to engines remanufactured by independents. Chris Hancock confirms that remanufactured products can be considered 'as good as new'.

> *Incidentally when I visited a remanufacturer who was part of a multi-national making brand new units and they tested the remanufactured unit against new. The remanufactured product was better but would they publicise that! Of course not, what would their major VM customers say!!*[127]

The second dimension, market share protection, relates to the discussion of aftermarket strategies. Chapter Five has demonstrated that the after sales business is a profitable part of the automotive sector and therefore highly competitive. The research has shown that there is also strong competition between original equipment manufacturers undertaking remanufacturing activities and independent remanufacturers. In the United States, the majority of remanufacturing firms are independent. This may have been a reason for the fact that previous, mainly American contributions, have not particularly emphasised the issue of market protection by the OEM. In Europe, the composition of market players depends very much on the country (see, for example, Lewis, G., 1991) and the author believes that automotive OEM remanufacturing (vehicle manufacturers and first tier suppliers) plays a more dominant role than in the United States.

According to interviewees, Case Company A did initially not perceive competition from the independent sector as an issue, but began to notice that a significant amount of aftermarket sales was taken up by independent remanufacturers, rather than by the sale of their OE replacements (as outlined in Section 10.2.3; quote by Brian Ludford). Company A's remanufacturing guide for retailers has therefore clearly pointed out the motive of obtaining and securing a share of the remanufacturing market:

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[127] Quoted from personal communication (letter) with Chris Hancock, the editor and publisher of several practitioner and industry journals such as *Engine Repair and Remanufacture* and *Vehicle Electrics and Electronics: Diagnostics and Emissions*, Rye, UK, January 2004. See full interview in Appendix G, Key Interview 5.

> *For many years, the independent players have given us a hard time in the remanufacturing sector. We think it is time to launch a counterattack: with competitive prices for original remanufactured products, in other words, remanufactured engines, remanufactured gear units and other exchange parts. Additionally, there is the even more favourable factory overhaul. If we can communicate this extended range of products and services successfully to our customers, we can, bit by bit, regain an important business. And you* [retailers] *get back profits.*
>
> (Company A/B, 2000, p. 1, translated from German)

The key to achieve both objectives, brand and market share protection, seems to be the core collection, or, as it has often been termed in interviews, the 'cleaning of the market'. Hauser and Lund (2003) have described cores as "[...] the lifeblood of the remanufacturing cycle" (p.1), which remanufacturers see as a critical factor with regard to growth. This dissertation has confirmed the reason 'cleaning of the market' from both sides. On the one hand, the vehicle manufacturer has outlined the importance of a thorough core collection:

> *Officially a remanufactured engine can only be bought if a core is returned. But if a customer offers us just the core without buying a remanufactured product, we tend to buy it anyway, because otherwise, the core would be 'food' for our competitors. With regard to commercial vehicle engines, at one point, we even bought back used engines from scrap yards to avoid that competitors would get hold of them.*[128]

On the other hand, independents have pointed out the significance of core supply to their activities in the questionnaire survey. Several anecdotes were told in interviews in which respondents reported that OEMs would scrap engine cores under supervision or even sent employees to 'clean' scrap yards.

Moreover, the scrapping of 5,000 engine cores at Company A's remanufacturing plant in 2001 showed that the vehicle manufacturer preferred to accept financial losses through scrapping, rather than providing competitors access to cores. Case Company

[128] Quoted from the interview with the Manager for Customer Process Management at Case Company A's Headquarters, September 2002, translated from German.

A's remanufacturing guidelines for retailers illustrate the importance of an elaborated take-back system.

> *The repair and remanufacturing business for engines is subject to fierce competition. In this sector, our competitors benefit particularly from the opportunity of purchasing inexpensive used materials/cores on the free market. In order to strengthen our position, it is a requirement that our field organisations actively take back valuable used materials for engines and return these for remanufacturing. On the one hand, this procedure serves the purpose of withdrawing the market basis from our competitors. On the other hand, it secures our own foundation for production.*
>
> (Company A/B, 2000, handout 8/99, translated from German)

The handbook further states how to proceed with core returns. As a general rule, retailers shall accept any core, for which they will be refunded by the vehicle manufacturer. Even though the Case Company follows a strict 'exchange policy', in which a remanufactured product may only be purchased if a core is returned, the retailer handbook offers take-back of selected cores without a subsequent purchase of a remanufactured engine. As the research has shown, the key to achieve the two predominant objectives (market share and brand protection) is the core collection which is carried out aggressively by the OEM. Case Company A did not seem to dread any costs in this respect.

Brand protection and market share protection could also be identified as reasons for electronic device remanufacturing, however they did not seem as distinctive as within engine remanufacturing. This may have been based on the fact that on the one hand, electronic device remanufacturing has only been undertaken since the late 1990s. At the time of the research, the product group electronics was still in the introductory stage of its remanufacturing life cycle, as the panel discussion by the APRA has confirmed (see Chapters Five and Eight).

On the other hand, Chapter Eight has outlined that electronics remanufacturing is less visible and less 'obvious' compared to mechanical remanufacturing. The access to the market is often restricted for independent players, since software and design information is rarely available to independents. Chapter Five has discussed the phenomenon of 'reverse engineering'. However, there is a different form of market protection, which is

applicable to electronic device remanufacturing. Case Company B has expressed its interest to regain car parts which are related to security features of the car. Those are, for example, keys, the engine control unit, as well as navigation components. This also concerned very expensive parts and components, with high 'grey market' demand. Within the Case Company, there was the fear that these components would be repaired or recovered by independent remanufacturers so as to be sold on the aftermarket, where they would then compete with original spare parts. Concluding, market share and brand protection could be confirmed as motives for automotive remanufacturing for both product groups engines and electronic devices.

10.3.4 Customer Orientation

This section illustrates aspects, which have been summarised as 'broader market appeal' by Lund (1984a). Lund does not further illustrate this point. However, it may be assumed that the broader market appeal for customers includes the vehicle manufacturer's ability to provide spare parts for a reasonable period, at a reasonable price and within a reasonable time. Scott Parker, the President of *Remanufacturing Industries Council International* in 1999 (in Nagler, 1999) clearly points out the significant role of customers with regard to the remanufacturing of parts:

> *If you buy a car and eight years later can't get it serviced for a reasonable price because the manufacturer has discontinued a particular part, you'll remember it when you buy your next vehicle.*
>
> (Scott Parker, cited in Nagler, 1999, p.79)

One interviewee confirms:

> *One of the reasons why we remanufacture passenger car engines and engines for small commercial vehicles is the fact that we want to offer the customer the option to purchase remanufactured engines. It all boils down to customer orientation and customer satisfaction.*[129]

[129] Quoted from the interview with the Manager for Customer Process Management at Case Company A's Headquarters, September 2002, translated from German.

Nagler (1999) therefore claims that the production of parts which can be remanufactured economically is one way to promote serviceability. According to BMW Info Service (2003) vehicle manufacturers are legally obliged to provide spare parts for 10 years. Producers of luxury vehicles, however, have voluntarily extended this period to 15 years, with an even further coverage in the classic car or military segments. Kiff and Chieux (1998) explain that customers appreciate an extensive service and repair network 'just in case'. The same may be true for an extended aftermarket product range.

> *...for consumers, the ideal is to have no servicing or repair at all, but they do expect and require the availability of a service and repair network 'just in case'. In addition to this, the process of having their cars professionally checked promotes a feeling of security in consumers.*
>
> (Kiff and Chieux, 1998, p.23)

Consequently, Case Company A provided a more extensive product range, including remanufactured products. For the case company's retailers, the take-back and remanufacturing of used engines had further advantages. On the one hand, the VM took care of the used product. Hence, retailers saved waste disposal or scrapping costs. This may have been beneficial in cases in which engines were seriously damaged and could not be remanufactured. On the other hand, retailers may have benefited from good quality spare parts at reduced prices. The significant price advantages for remanufactured products was calculated and discussed in Chapter Six.

Moreover, from an end-user perspective, the company provided a 'just in case' stock of remanufactured spare and replacement parts for one of the main target groups, including fleet managers and mailing companies. The availability of exchange products 'just in case' the customer may require a remanufactured engine may have influenced the buying decision as outlined by Scott Parker (in Nagler, 1999).

The customer process manager at Company A's Global Warehouse, stated that "the company hardly makes any profit on remanufactured engines". The interviewee explained that customer orientation was one of the predominating reasons for the group to engage in the remanufacturing of engines. A further way of demonstrating customer orientation was the extension of the existing spare parts product range by remanufactured products.

> *For the OEM, remanufacturing offers several additional benefits. If there is price elasticity in its product markets, an OEM may be able to offer remanufactured versions of its products at substantially lower prices. This can broaden market appeal and increase overall sales. (For products in an inelastic market the converse can be true – remanufactured goods could cut into new product sales.) Arrangements for good trade-in prices for old units create customer loyalty to the company's brands. By controlling remanufacture of its products a company also protects the reputation of its brand or trademark from inferior workmanship.*
>
> (Lund, 1984a, p.55)

A further concept of customer orientation was the ability to provide an exchange, which indicates a short waiting time for the customer. In this section, the time to fulfil orders from the retail level will be discussed. According to interviewees, the assembly of an engine, whose original high-volume manufacturing line has been closed down, can take up to six months if the engine is sought to be build entirely from new parts. This timeframe is determined by the procurement of the engine's parts, which are, as previously noted, often hand-made or low-volume productions. Building such an engine from brand-new parts is therefore not only significantly more expensive than remanufacturing, but additionally requires a long time to be completed. The customer, however, is not prepared to wait several months for a replacement engine. Despite the fact that there is a significant buffer of 8,000 finished engines at the corporation's Global Warehouse, the stock replenishment cycle is shorter for remanufactured replacements, compared to phased-out engines which have to be manufactured from new parts. Remanufacturing is therefore the less expensive and faster option for replenishing the company's safety stock with regard to older engines.

Concluding, several aspects of customer orientation which have been discussed in this section have contributed to the establishment of product take-back and remanufacturing networks in the automotive sector.

10.4 Summary

Tables 62 and 63 summarise this chapter's discussion.

	Reasons for Automotive Remanufacturing	Degree of Influence to Induce OEM Engine Remanufacturing	Findings
Motives Identified in Chapters Two and Three	Ethical/ moral responsibility	Low	▪ No emphasis on promoting the eco-friendliness of remanufactured products ▪ The green consumer group or 'green marketplace' could not be identified' ▪ Anti-remanufacturing' attitude of VMs discovered
	Legislation	Low	▪ History of engine remanufacturing is based on other reasons ▪ ELV Directive does not account for remanufacturing ▪ The research has discovered further, predominant reasons
	Direct profitability/ Profit maximisation	Low	▪ High uncertainty in core acquisition: scrap rates ▪ Strategy 'cleaning market' from cores increases core prices (competition for cores) ▪ Necessity to incorporate expensive new parts ▪ High labour costs
New Observations	Information feedback	Low	▪ No feedback to new product design; potential reason may be long engine life cycle ▪ No 'design for remanufacturing' ▪ No co-operation between engineers from remanufacturing and serial production
	Secure spare parts supply	High	▪ Decreasing dependency on suppliers with regard to prices and spare parts availability ▪ Remanufacturing is, in some cases, the only source of spare parts ▪ Remanufacturing of phase-out engines is technically and economically more viable than a reproduction ▪ Balancing engine aftermarket demand through remanufacturing
	Warranty	High	▪ Important source of under-warranty engines
	Market share and brand protection	High	▪ Controlling quality of remanufactured engines ▪ Building 'quality image' for own products by promoting employee skills and sophisticated equipment ▪ Thorough core collection as universal key to excluding independents
	Customer orientation	High	▪ Availability of extensive, reasonably priced aftermarket range, 'just in case' ▪ Vehicle manufacturer takes care of used units ▪ Stock replenishment time reduction

Table 62: Reconciliation of Research Questions and Research Findings: Reasons for OEM Remanufacturing - Engines

	Reasons for Automotive Remanufacturing	Degree of Influence to Induce OEM Electronic Device Remanufacturing	Findings
Motives Identified in Chapters Two and Three	Ethical/moral responsibility	Low	▪ Interviewees did not provide evidence to support the moral or ethical reason ▪ Further predominant reasons were identified (e.g. warranty)
	Legislation	Low	▪ History of electronic remanufacturing is based on other reasons ▪ WEEE does not particularly refer to automotive electronics ▪ The research has discovered further, predominant reasons
	Direct profitability/ Profit maximisation	Low	Emphasis is put on 'avoiding further costs' with regard to: ▪ Saving warranty costs ▪ Remanufacturing is one step further away of failure cause identification within the warranty adjustment process
New Observations	Information feedback	Low	▪ Not in environmental terms; design-for-environment often not considered
		High	▪ Feedback to current assembly line ▪ Identification of 'true' product failure rate: 'quota of recourse'
	Secure spare parts supply	High	▪ Economically viable source of spare parts in cases of product termination ▪ Extension of spare parts range
	Warranty	High	▪ Making sensible use of warranty returns: NFF devices of vehicle manufacturer, SF devices of supplier ▪ Opportunity to benefit from warranty adjustment process
	Market share and brand protection	High	▪ Regaining of security-related parts ▪ Thorough core collection ensures the 'containment of the grey market' ▪ Excluding independents, whose products compete with original spare parts
	Customer orientation	High	▪ Offering a complete aftermarket range of products

Table 63: Reconciliation of Research Questions and Research Findings (VM and Supplier): Electronic Devices

10.5 Conclusion

This chapter has reviewed Research Questions 3 to 5. These research questions referred to the main motives that the literature provides as explanation for the rationale behind product take-back and recovery. This thesis has tested three reasons for remanufacturing: ethical and moral responsibility, product take-back and recovery legislation as well as the direct economic motive (profitability of remanufacturing). These three main reasons for product recovery in general and remanufacturing in particular had been developed Chapter Three. Within the research they were tested for their applicability onto the automotive remanufacturing sector.

This chapter has outlined and summarised the findings. It became clear that with regard to OEM remanufacturing and with regard to both product groups (engines and electronic devices) the degree of influence to induce remanufacturing was low for the three motives. Section 10.2 have explained in detail why it can be assumed that the role of these three motives within the establishment and undertaking of OEM remanufacturing has to be considered as low. Tables 62 and 63 have summarised the discussion. Even though ethical and moral responsibility, environmental legislation and the direct economic motive may have had a low influence on OEM automotive remanufacturing, it may be assumed that these factors may be reasons for remanufacturing in other industry sectors, for different product groups or cases.

With regard to this research, a variety of other aspects that have motivated and supported OEM remanufacturing were discovered. These findings have been outlined and discussed in the second part of the chapter and summarised in Tables 62 and 63.

Since motives for remanufacturing seem to differ with regard to the player in the market, the product and the country, present and future research needs to account for all different cases rather than providing general assumptions. The research findings also need to be considered within the establishment of remanufacturing models, since 'general' scientific assumptions do not apply to all products and all players at all times.

Chapter Eleven Conclusions and Recommendations for Future Research

11.1 Introduction

This chapter concludes the thesis. It firstly explains how the research was delineated. In other words, it will be outlined what this research has investigated and what has been omitted. It hereby justifies why and how these delineations were made.

Secondly, the research questions will be reviewed and the aims and objectives of the research will be summarised. The chapter also discusses to what extent these objectives could be fulfilled with regard to a contribution to the related and immediate fields of knowledge. More clearly, the chapter demonstrates how the research has developed and extended the understanding of the parent discipline of closed-loop supply chain management and the immediate fields of product recovery and remanufacturing management. Moreover, the contribution to theory is outlined. Since this research aimed to provide elements for a theory for closed-loop supply chain management, the contribution this research has made will be summarised. In addition, it will be shown

how theories from related disciplines may benefit from the results of this research. Thereafter, the methodological contribution, which has been outlined in Section 4.3.4 is summarised.

The chapter concludes with a discussion on how this research may form future research in the field, but also which implications for industry may be drawn from the research. Hence, the needs with regard to future scientific research, but also suggestions for industry are proposed.

11.2 Purpose of the Research

11.2.1 Overall Line of Enquiry

This thesis has investigated closed-loop supply chain management with an emphasis on OEM remanufacturing in the automotive sector. Closed-loop supply chain management has been identified as a progression from reverse logistics research in Chapter Two. Since the narrowness of previous research has been criticised by various contributors (e.g. Guide *et al.*, 1999; Van Hoek, 1999), a holistic view was taken by this research. The research focused on the remanufacturing of end-of-life products. There were several reasons for this delineation of scope.

Firstly, in Europe, end-of-life product returns seemed to be the most prominent category of product returns (Fleischmann, 2001).[130] Further contributors have expressed general issues which companies face with regard to end-of-life or end-of-use products (e.g. Toffel, 2003; Geyer and Jackson, 2004).

Secondly, the two European regulations, the ELV and the WEEE Directive, have furthermore stressed the need for a focus on end-of-life product treatment, since they aim at the take-back and recovery of products at the end of their lives.

Thirdly, the focus on remanufacturing, as the only product recovery operation which was investigated within this research, was supported by the high-quality production

[130] As outlined in previous chapters, this is not true for the United States. Closed-loop supply chain experts have claimed that commercial returns are perceived as more significant in the United States than in Europe. See, for example, Blackburn *et al.* (2004).

outputs this operation provides, the environmental contributions it may achieve as well as the operational complexity remanufacturing provides for scientific research (see Chapters Two, Three and Five). In the course of the research, it also became clear that remanufacturing is also the recovery operation that is most likely to achieve a nearly closed, genuine loop.

The research has furthermore focused on the European, but very much on the German automotive sector. There were two reasons for that. Firstly, most of the previous empirical research on remanufacturing has taken a North American perspective (e.g. Lund, 1996; Hauser and Lund, 2003). Secondly, the proximity of the case companies has played a role in the selection of the European sector. Moreover, the regulations which were thought to have an impact on the automotive sector had been enacted by the European Commission.

The selection of the automotive sector has been based on further factors. Firstly, Chapter Three has shown that legal and social pressures have always played a significant role within this industry. Moreover, the review of literature has demonstrated that research on the automotive remanufacturing sector tended to be part of larger studies on remanufacturing, was limited to a practitioner audience, or solely focused on the American sector (e.g. Lund 1984a, 1984b, 1996; Steinhilper, 1998, 1999; Steinhilper and Hudelmaier, 1993). Only few examples with an in-depth automotive focus were discovered, yet most of these have taken a narrow perspective on one particular issue of remanufacturing rather than a holistic closed-loop supply chain perspective (e.g. Amezquita and Bras, 1996; Hormozi, 1997; Hammond *et al.*, 1998; Sherwood and Shu, 2000).

The research has taken a qualitative, empirical and exploratory route. This was based on the following conclusions. Firstly, much of the existing research on remanufacturing has been of a quantitative nature, such as the contributions by key researchers in the field (e.g. Ferrer, 1997a, 1997b; Guide and Srivastava, 1997; Van der Laan, 1997; Guide *et al.*, 2003b; Van der Laan *et al.*, 2003). Secondly, the need for more empirical research has been demanded by precisely these contributors, who have admitted that more case studies are necessary to bridge the gap between theory and practice (Van der Laan *et al.*,

2003) and that previous research has lacked in documenting present industry practices in case studies (Guide *et al.*, 1999). The case study research on electronic device remanufacturing may even be classified as completely new to the scientific community, since, at the time of the research, it has been recognised as one of the most recent developments in the automotive remanufacturing sector. Hence, a combined approach of qualitative, empirical and exploratory research has been perceived as most beneficial for one of the main aims of this research: the attempt to provide elements for a theory for closed-loop supply chain management (see Chapters Three and Four). However, although the area of automotive remanufacturing cannot be perceived as a completely new field of research, the combination of the above factors has resulted in a unique approach to the research problem.

11.2.2 Research Questions

This dissertation investigated five research questions. The first two research questions were developed in Chapter Two. They referred to closed-loop supply chain management and remanufacturing structures in the automotive industry. Research Question 1 was based on the lack of applicability that existing closed-loop supply chain structures provided for automotive remanufacturing. It therefore asked for the appropriate closed-loop supply chain structure for automotive remanufacturing. The empirical grounding for the answering of this research question was discussed in Chapters Six and Seven. From this empirical framework, a new terminology for closed-loop supply chain management was developed in Section 9.2.1. Thereafter, the first research question could be answered by the presentation of two very specific OEM automotive closed-loop supply chains, focusing on remanufacturing (Section 9.2.2).

Since this research has clearly differentiated between the holistic closed-loop supply chain perspective and the recovery operation as one echelon of this supply chain, the second research question sought to examine existing remanufacturing process structures with regard to their applicability to the automotive remanufacturing sector. Two specific remanufacturing process structures were developed from the empirical research (Sections 6.4 and 7.6.2). The research question also comprised a discussion of the major issues and obstacles which can be found within these remanufacturing processes. Hereby, the current debates in the literature (Chapter Two) and the challenges the

literature suggests (Section 9.3.1) were compared with the issues and obstacles that were discovered during the fieldwork (Section 9.3.2). The discussion related to Research Question 2 was summarised in Table 61.

The three additional questions, Research Questions 3, 4 and 5, referred to the reasons for product recovery. More accurately, they sought to test three specific motives which had been assumed in the literature, within an automotive remanufacturing environment. Research Question 3 investigated whether moral or ethical responsibility has been a main driver for the OEM to establish and undertake automotive remanufacturing operations. For both product groups the role of moral or ethical responsibility as decisive factor within the motivations for OEM remanufacturing had to be considered as minor (see Section 10.4). Research Question 4, which aimed to test product take-back and recovery legislation as a motive for remanufacturing and Research Question 5, which asked whether direct economic motives are main reasons for automotive remanufacturing were also identified as motives with a low degree of influence on the establishment of OEM remanufacturing. Instead, this research has provided an extensive new set of motives that played a major role within the establishment and management of OEM automotive remanufacturing. These new motives included the ability to provide spare parts over the whole car life cycle, the provision of under-warranty replacements as well as well as market share and brand protection. However, it needs to be considered that these findings are specifically related to the cases that were investigated, the specific players in the market (OEM) and the automotive sector. Future research may therefore perceive this rationale for automotive remanufacturing as starting point for further investigation.

11.2.3 Aims and Objectives of the Research

The dissertation sought to contribute to the development of the field in three different ways. Firstly, initial research findings have shown that current closed-loop supply chain and remanufacturing models were not applicable to the automotive industry. As a result, the research aimed at the creation of automotive closed-loop supply chain and remanufacturing structures which may serve as basis for further research (scientific

contribution). Secondly, Section 3.2 and Section 4.3.2 have demonstrated a need for the development of a closed-loop supply chain theory (theoretical contribution). Thirdly, the unique combination of methodological elements has resulted in a methodological contribution.

Contribution to Related and Immediate Scientific Fields

This section discusses the contribution this dissertation has made to the parent discipline of closed-loop supply chain management and to the immediate field of product recovery and remanufacturing management.

Chapter Two has criticised that previous closed-loop supply chain structures have taken simplified views by integrating return flows from product recovery operations (e.g. remanufacturing, recycling) back into the 'forward' supply chain. The classic example is the model presented by Thierry *et al.* (1995), on which many subsequent contributors have based their ideas (e.g. Guide *et al.*, 1999; Majumder and Groenevelt, 2001b; Meade and Sarkis, 2002; Mahadevan *et al.*, 2003). These models have all assumed a general 'forward' supply chain from raw material over parts fabrication, modules assembly, product assembly and distribution to the customer or user. However, the major critique of these models was the assumption that materials or parts re-enter this forward supply chain after recovery at specific points. Even very recent publications still support this classic closed-loop supply chain structure (e.g. Krikke *et al.*, 2004). However, since the application of these models onto the automotive remanufacturing sector has been unsuccessful, the first research question was created. This research question asked for the identification of the appropriate closed-loop supply chain strategy for the automotive sector.

The real-world closed-loop supply chains have been portrayed and discussed for engines and electronics (see Chapters Six and Seven). More generally, the discussion has raised further questions with regard to the terminology of 'open' and 'closed' loops and to what extent these may be closed. The contribution to the parent field of closed-loop supply chain management therefore comprised two elements. Firstly, Chapter Nine has

developed and defined the key terminology for closed-loop supply chain management. Based on the framework in Chapter Nine, the second contribution implied the application of the terminology onto the two specific closed-loop supply chain models which had resulted from the research. In other words, this research has not supported previous models in the area of closed-loop supply chain management, but needed to develop industry-specific and more precise models with an indication of industry players and the supplementation of industry data. Although some contributors have come to the conclusion that there is the need for industry-specific, rather than general closed-loop supply chain models (e.g. Guide and Van Wassenhove, 2003c), others still insist on the validity of the classic models (e.g. Krikke *et al.*, 2004). Hence, the insights gained from Research Question 1 may serve as a basis for further investigation in the automotive sector, but may also serve as blueprint or reference value to other industries.

Research Question 2 referred to the development of a specific automotive remanufacturing model. Although there has been academic research on remanufacturing, much of it has been limited to a specific area, such as core acquisition (e.g. Ferrer, 2001; Guide *et al.*, 2003b; Toktay *et al.*, 2003b), inventory management (e.g. De Brito and Dekker, 2003b; Mahadevan *et al.*, 2003) or shop floor control (e.g. Guide *et al.*, 2003a; Inderfurth and Teunter, 2003; Kiesmüller *et al.*, 2003).

Moreover, contributors in the area tended to indicate the remanufacturing plant as a box within the closed-loop supply chain, labelled 'reprocessing' (e.g. Krikke *et al.*, 2003), 'remanufacturer' (e.g. Guide and Van Wassenhove, 2003a) or 'component recovery' (e.g. Spengler and Schröter, 2003), rather than discussing the processes in detail. In some cases, the understanding of closed-loop supply chain and in-plant recovery process have even become indistinct (see, for example, Krikke *et al.*, 2003, p.3697).

Contributors who have developed remanufacturing models presented generic models (e.g. Guide, 2000), but also more specific models on photocopier remanufacturing (e.g. Kerr and Ryan, 2001), refrigerator recovery (Krikke *et al.*, 2003) or personal computer remanufacturing (Ferrer, 1997a). However, the main contributors within the area of automotive remanufacturing, Van der Laan (1997) and Langella (2003), have not particularly focused on actual in-plant operations. As a result, there are few examples in

which in-plant automotive remanufacturing processes have been discussed, such as Steinhilper (1998), who targets a practitioner audience and the generic model for automotive remanufacturing presented by Ferrer and Whybark (2001), which lacks in detailed process data. Hence, there was the need for the investigation of in-plant automotive remanufacturing processes with detailed process data. As a result, this research has taken a holistic approach by displaying the complete closed-loop supply chains for car engines and electronic devices, yet the research also investigated the activities inside one of the closed-loop supply chain echelons in more detail.

In Chapter Two, it was demonstrated that various contributors have expressed the needs for more empirical research in the field of remanufacturing. This research did not just aim at the development of automotive remanufacturing models, but also sought to build a bridge between real-world issues and the scientific community. As a result, the real-world remanufacturing process structures serve as empirical, real-world starting-points for future scientific research and may lead to an information feedback to the remanufacturing industry. In other words, even though the obstacles and uncertainties within remanufacturing (see, for example, Table 61 in Section 9.4) are specific to the automotive sector and the case companies, future research may further examine these findings and create new approaches to problem-solving. Since this dissertation's findings were developed from real-world research, they are more suitable for academic enquiries than the current, quantitative approaches which take abstract assumptions and models as the basis for research. Concluding, a further development of the immediate research environment was achieved by bringing real-world research and real-world issues into a scientific community.[131]

[131] Hence, some of the research results have therefore been published in an environment which targets the practitioner, but also the academic audience (see Seitz and Peattie, 2004).

Contribution to Theory

Chapter Three has outlined the characteristics of a theory. A theory has been defined as a set of statements which are seen as valid with regard to certain phenomena (Zikmund, 1994; Keating, 1995). Whetten (1989) further adds that data characterise, but only theory supplies the explanation for these characteristics. In Chapters Two and Three, it was demonstrated that although closed-loop supply chain management originates from a relatively mature 'mother' discipline (supply chain management), it has been provided with a far less theoretical grounding than researchers would have assumed. Chapter Two has also outlined that previous research on closed-loop supply chain and product recovery management has commenced to discuss issues that are similar to the current debates in the parent discipline, rather than questioning whether the same 'rules' and assumptions are valid in the new discipline.

Due to the fact that the discipline of closed-loop supply chain management is perceived as relatively young, and based on the observation that theory-building in this area has not been identified as a major objective on the research agenda for closed-loop supply chain management, Chapters Two, Three and Four have confirmed that there is the need to identify an appropriate theory for this area.

Keating (1995) has claimed that the process of theory discovery aims to map novel, dynamic or complex phenomena, which have been ignored, inadequately addressed or explained by existing theory. With regard to this process, Stuart *et al.* (2002) demand a review and assessment of knowledge in related fields in order to exclude fatal research process errors. Consequently, this dissertation has evaluated existing theories and concepts from related fields. A particular emphasis was put on industrial ecology theory, systems thinking, and more generally, on corporate social responsibility and sustainability.

According to Whetten (1989), and initial, rudimentary theoretical statement needs to contain three elements, the *'what'* (variables, constructs, concepts), the *'how'* (causality, relationships, patterns) and the *'why'* (dynamics of relationships, explanations). With regard to this research, the *'what'* of the theory refers to factors which are affected by

the theory, such as the players involved in closed-loop supply chain management (customers, remanufacturers), but also variables as, for example, the reverse logistics process. To ensure that all relevant factors are included, Whetten (1989) recommends the mapping of the conceptual landscape. Within this research, this was undertaken in Chapter Two.

The review of industrial ecology theory and systems thinking has provided ideas for the identification of the *'how'* and the *'why'* of a closed-loop supply chain management theory. Firstly, the *'how'* element of the theoretical statement was enquired through Research Questions 1 and 2. With regard to the theoretical explanation, industrial ecology theory has presented a framework for the relationships and causalities within closed-loop supply chain management in the idea of the endless, repetitive materials cycle or the 'industrial metabolism' (Section 3.2.3). Chapter Two has discussed various closed-loop supply chain management models in which this idea was pictured (Section 2.4.2). Hence, industrial ecology has contributed to the understanding of material and product flows, how actors of the closed-loop supply chain are linked and how they interact. Secondly, this theory has provided a set of tools to measure these flows, such as life cycle analysis or physical input- output accounting. Although these tools were not applied within this research, future research may consider the use of such methods in order to measure inefficiencies within remanufacturing closed-loop supply chains and thereafter to eliminate these.

Systems thinking has contributed the definitions of closed and open systems to the *'how'* aspect of the initial theoretical statement. With elements taken from systems theory, a new terminological framework for closed-loop supply chain management was developed in Section 9.2.1. In addition, systems thinking has encouraged and enforced a holistic view on this research. In other words, although the remanufacturing processes were examined separately, the research has investigated the closed-loop supply chains as a whole, also with regard to the relationships between the individual echelons of the chain.

Considering the *'why'* of an initial and rudimentary theoretical statement for closed-loop supply chain management, none of the two theories or the two concepts (corporate social responsibility; sustainability) could provide explanations for the observed phenomena.

Firstly, there were three research questions which sought to identify the rationale behind remanufacturing and closed-loop supply chain management in the automotive sector (*Why* are original producers involved in such activities?). Corporate social responsibility suggested that the one potential reason for a company's involvement in corporate greening (e.g. product recovery) is moral or ethical responsibility (Toffel, 2004). The presentation of research results in Chapters Six, Seven and Eight, as well as the interpretation and summary of these in Chapter Ten have demonstrated that moral and ethical responsibility had to be considered as motives with a low degree of influence to induce OEM remanufacturing for engines or electronic devices.

Secondly, industrial ecology theory, as the term says, assumes that there is a willingness of the actors to be 'ecological' (Lifset and Graedel, 2002) and that they strive to 'maintaining a desirable carrying capacity' (Allenby, 1999). Hence, industrial ecology theory assumes that underlying environmental motives play a role in corporate decision-making. However, contributors in the area of industrial ecology are aware of legal constraints and boundaries in which they are operating (Allenby, 2002). This research has demonstrated that environmental legislation (e.g. the ELV Directive) also had to be considered as a motive with a low degree of influence to induce OEM remanufacturing. As a result, assumptions within the main debates of the environmental social sciences could not provide sufficient explanation for the rationale behind automotive remanufacturing.

With regard to the last research question, the role of direct profitability in automotive remanufacturing, an explanation was sought to be found within systems thinking. Within systems theory, there is the underlying assumption that each corporation seeks to achieve financial efficiency through the elimination of ill-structured problems (Checkland, 1981). This research has identified a large number of obstacles and issues within the remanufacturing operations, however, the direct economic motive could not be confirmed as main reason for the OEM's interests in remanufacturing. Guide *et al.*

(2003b) have confirmed that the role of profitability has not been adequately addressed by previous research. This research has confirmed a low degree of influence for the direct economic motive to induce OEM automotive remanufacturing. However, future research needs to address the role of profitability within other scenarios and cases. Although systems thinking could not provide the rationale for OEM automotive remanufacturing, it may provide tools and methods for solving the problems that this dissertation has discovered. In other words, systems theory may not have been able to explain why automotive remanufacturers engage in the activity, but it presents structured methodological approaches to solve the identified issues. A good case in point is the methodology of 'action research', as suggested by Checkland (1981). While this dissertation has provided a description and analysis of current real-world problems within automotive remanufacturing, systems thinking may provide abstract, but structured changes in order to improve the system.

Consequently, this dissertation has made a theoretical contribution by presenting explanations for the *'what'*, *'how'* and *'why'* elements of the rudimentary theoretical statement for closed-loop supply chain management. Research results by contributors in related areas, which occurred in the course of this dissertation, confirm that the question of the rationale (*'why'*) behind product recovery is significant issue of interest for which no universal explanation or answer has been found. Toffel (2004) has been one of the first contributors who specifically investigated the motives for voluntary product recovery. While he still maintains the 'classic' motives for product recovery (reduction of production costs; promoting an image of environmental responsibility), he has also discovered novel motives, such as meeting customer demands, protecting aftermarkets and pre-empting regulation. Novel to the discipline of closed-loop supply chain and product recovery management are also the discoveries made by this dissertation. Chapter Ten has provided a detailed list of motives which were considered as factors with a low degree of influence to induce OEM remanufacturing with regard to the automotive sector, but has also provided a variety of novel motives. Although these motives are specific to the OEM automotive remanufacturing sector, future research may validate or decline the elements of this rationale for other industry sectors, cases or product recovery options.

Secondly, the research has not only described issues and obstacles within remanufacturing, but also explained why these occurred, which is a central element to theory-building (e.g. Whetten (1989). As an example, this research has described the issue of warehouse management, but has also outlined a variety of sources for these obstacles (e.g. product variety). Moreover, it was explained why the case companies, particularly the OEM engine remanufacturer, have not made specific attempts to improve their operational processes.

It may therefore be argued that due to the fact that previous contributors have based their research on the 'classic' assumptions (motives for product recovery), such as the direct economic motive, there have inevitably been research outcomes which were related to these assumptions, such as optimisation models for disassembly, core acquisition and scheduling. However, if contributors had known that for some industry players, such as the OEM, motivations for remanufacturing differed, they would have developed different models and hence, current research would have provided different research outcomes. As an example, had previous contributors known that OEM remanufacturers may not consider optimising their core disassembly or core acquisition processes due to the fact that their rationale was not entirely based on the direct economic motive, they would have also known that the overall role of remanufacturing within these corporations is rather negligible. Hence, overall optimisation may not have been their main objective, but they would have requested the design of a flexible production system that is able to handle the uncertainties within remanufacturing. Potential research outcomes could have been the design and testing of lean remanufacturing principles, or the 'remanufacture-to-order' approach within OEM remanufacturing.

While the above theoretical contributions may be seen as the first elements to an initial, rudimentary theory for closed-loop supply chain and product recovery management, contributions could also be made to the theory of a related field, industrial ecology theory. Chapter Three has shown that the theory comprises the total materials cycle from cradle to grave (e.g. Allenby, 1999). Moreover, Chapter Three has outlined that there is an ongoing debate whether ecology can be taken as a blueprint for the design of

sustainable business strategy. According to Allenby (1999), a 'perfect' ecosystem receives energy input from the sun, while all other materials are recycled biologically. However, Allenby (1999) also confirms that this is a highly idealised assumption to be applied to an industry.

This research has shown that, in fact, there is a far broader spectrum of how materials flow, as the discussion on simple, extended, fully and nearly closed-loop systems has summarised (in Section 9.2). Moreover, Chapter Nine has demonstrated that remanufacturing processes produce waste which may not necessarily serve as a raw material for the same or other processes. Since companies generally tend not to aim for the 'maintaining of a carrying capacity', the application of eco-mimicry has been rather unsuccessful in the automotive remanufacturing sector.

Moreover, Chapter Three has pointed out that a pure material life cycle perspective may be too narrow. Elkington (1994) has outlined that many of the environmental problems are being 'imported' through the supply chain, which may particularly apply to the automotive supply chain with thousands of suppliers, many of them unknown to the vehicle manufacturer (Brunnermeier and Martin, 1999). With the involvement of the end-customer or end-user, a product life cycle perspective, as suggested by Boons and Baas (1997), seems to be more suitable for similar research problems. As a result, a contribution towards industrial ecology has been made by the in-depth documentation of product recovery cycles which have demonstrated that industry practice differs to a great extent from what has been identified as a perfect and idealised industrial ecosystem. The findings may therefore be considered in re-shaping ideas within the field of industrial ecology.

Contribution to Methodology

Chapter Four has explained that the methodological element of a paradigm indicates how the researcher gains knowledge about the world. In other words, methodology comprises the combination of tools and techniques that have been applied to the research, which also includes the specific data collection methods.

The methodological considerations for this research have been outlined in Chapter Four. They can be summarised as the application of inductive thinking and grounded theory to

an in-depth, holistic and multiple case-study research strategy. The research has begun exploratory and descriptive, but gradually become more normative. The data collection methods included unstructured and semi-structured interviews, process observation and questionnaires.

The methodological contribution of this research is based on the fact that although it may be argued that specific elements of this research on automotive remanufacturing have been investigated by previous research, the combination of these elements must be seen as unique. Section 4.3.4 has demonstrated that relevant research in the field of remanufacturing has often taken a broader view by examining a variety of industries simultaneously (e.g. Guide, 2000; Guide and Van Wassenhove, 2003c; Hauser and Lund, 2003). Those who have taken an in-depth focus on the automotive sector have applied different main data collection methods, such as questionnaire surveys (e.g. Hammond *et al.*, 1998) or mathematical modelling (e.g. Van der Laan, 1997; Langella, 2003). The few examples on automotive remanufacturing have taken a single case study approach, with logistics focus (e.g. Johannes, 1995) or a disassembly focus (Langella, 2003), rather than a closed-loop supply chain perspective. Hence, by taking an in-depth focus on the remanufacturing operations, but likewise emphasising the whole context of closed-loop supply chain management, this research has contributed to methodology.

Moreover, previous research has largely applied deductive thinking to research. Deductive thinking is characterised by working from the theory over the observation to the confirmation or denegation of the hypotheses. Within closed-loop supply chain management, the deductive approach to research has often led to a narrow focus on the local optimisation of specific operational issues, which has already been criticised by Guide *et al.* (2003b). This may be due to the fact that most of the contributors in the field originate from a background with solid modelling skills, as De Brito *et al.* (2003b) have discovered.

However, the focus on quantitative, structured and rather experimental research stands in sharp contrast to the needs of theory-building which have been pointed out and discussed in Chapters Three and Four. Although it may be argued that the research on closed-loop supply chain management is less developed and that there is the need for the

development on a theory for this discipline, previous contributions have aimed at the optimisation of individual aspects (see Section 2.5.5 in Chapter Two) by applying tools and techniques which Whetten (1989) and Handfield and Melnyk (1998) have recommended for theory refinement and extension, rather than theory development. Hence, this research contributes to the methodological understanding of closed-loop supply chain management by the tools, techniques and perspectives that were used, compared to those that are usually applied in academic research on remanufacturing. In this way, a methodological contribution was achieved, since the researcher has gained knowledge about the same world (remanufacturing; closed-loop supply chain management) through different methodological considerations. On the one hand, the unique application of methodology resulted in new research findings. On the other hand, this research confirmed results which were published by contributors who have applied different tools and techniques to gain the knowledge about the specific field of research.

The methodological contribution also refers to the fact that this dissertation has taken an interdisciplinary perspective. It has combined the world of product recovery management, which has mostly taken a supply chain management or operations management perspective, with the disciplines of the social sciences. There are examples in which contributors have sought to combine these two perspectives (e.g. Martin, 2001; Guide and Van Wassenhove, 2002a). However, the idea of combining the focus of environmental performance (e.g. industrial ecology, sustainability) with a supply chain management perspective (closed-loop supply chains; reverse logistics) is a new idea (e.g. Geyer and Jackson, 2004). The benefit of such a combined approach is the development of interdisciplinary, real-world assumptions for scientific research.

11.2.4 Recommendations for Future Research

Although this research has developed various starting-points and new ideas for future research, such as the optimisation of in-plant engine remanufacturing processes, this section only points out main recommendations for future research. Firstly, the application of lean philosophies on a remanufacturing environment are discussed. Secondly, this section outlines how the results of this research have developed into implications for current industry practice.

Operational Perspective: Lean Remanufacturing

The application of lean principles onto remanufacturing processes has just recently gained attention. The Lean Remanufacturing Workshop at the ReMaTec 2003, for example, aimed at raising 'lean awareness' among remanufacturers, by introducing them to the benefits of the application of lean principles (Fargher, 2003b). According to Fargher (2003b), lean remanufacturing is the identification and elimination of non-value-added activities through continuous improvements within a remanufacturing environment. He has outlined various benefits of lean remanufacturing, which are listed in the following.

- Reduction of remanufacturing turn-around-time[132]
- Improved on-time shipments
- Reduced work in progress
- Improved quality
- Reduced floor space

After solid research and documentation of the remanufacturing processes of gas turbine compressors, helicopter rotor blades and hydraulic components (Fargher, 1997), Fargher has presented a comprehensive introduction to lean remanufacturing at the ReMaTec 2003 (Fargher, 2003a). He discovered that a clear sense of urgency and willingness to change are essential elements to ensure the success of applying lean principles to a remanufacturing environment. Research efforts have also been made by Amezquita and Bras (1996). However, there is the need for more empirical research in this direction.

This research has discovered that there are a large number of 'wastes' (Sections 6.4.3 and 9.3.2) and thus, there should be an urgency for change within OEM engine remanufacturing. However, remanufacturers seem to be rather reluctant to changing their working practices. This phenomenon has been confirmed for the overall engine remanufacturing sector by Hadingham (2003a), who argues that engine remanufacturers are loath to adopting fundamental changes to their current practice (see quote in Section 5.4.2).

[132] Fargher (1998) defines the turn-around-time as the specific amount of time (in working days) which is required "to progress from induction to acceptance and packaging for storage or shipment to the customer" (p.x). This term is also called 'flow time' or 'repair lead time'.

Future research should therefore closely examine the overall remanufacturing process of one product, produce a map of the current state and improve the process by the use of lean tools and techniques (e.g. Bicheno, 2000). Should the results prove that the processes have significantly improved, a suitable production system for remanufacturing is found. This is particularly necessary, since the application of mainstream engine manufacturing onto a remanufacturing environment was found as unsuitable for high-volume remanufacturing processes.

Closed-Loop Supply Chain Management: Implications for Industry

Even though this research has mainly focused on one player in the sector and on one industry, there are two main groups of implications this research has developed for closed-loop supply chains in other industries. The first group of implications considers changes within the automotive sector, whereas the second approach investigates how other industries could benefit from the research findings. Both approaches are discussed in this section.

Firstly, there is the need for a distinction between engine and electronic device remanufacturing. Remanufactured engines take a more mature position in the market than remanufactured electronic devices, as it has been outlined at various places in the thesis. Hence, there are different implications for each of the product groups. In fact, the research has shown that the potential for growth seems to be rather limited with regard to engine remanufacturing. As Ludford (2004) has confirmed, this is also due to the high quality standards of engines today, compared to the standards of 30 years ago.

Although the research findings have shown great potential for improvement of the engine remanufacturing operation, various reasons have been outlined which may indicate that vehicle manufacturers have no intention to change their working practices. Other factors include the trend towards 'throwaway' engines (e.g. Phillips, 2001), the subordinate role of the engine remanufacturing operation within the corporation and the stagnant demand for remanufactured engines over more than a decade (see Table 38 in Section 6.3.2). Further factors, such as decreasing vehicle prices and competition (as outlined in Chapter Five) raise the question whether there is a future for OEM engine

remanufacturing operations with regard to broader market applications. However, it seems to be a different case for the classic car segment.

> *The remanufactured engine is not perceived as adding much value to the car. Residual values in premium and luxury cars of course stay higher for longer. Of the major manufacturers, Mercedes have long enjoyed the best resale values. The volume manufacturers achieve this only with some niche vehicles ('classics') such as Ford Cosworth Sierra. Where there is still high residual value, it is much easier to commit to the cost of repair. Certain prestige cars (Rolls-Royce, Aston Martin etc.) are maintained indefinitely.*[133]

Booth (2003) adds that remanufacturing engines for the classic car segment is also very profitable. "Because the car is their 'hobby' they pay well. No expense spared on their pride and joy unlike their day-to-day conveyance" (Booth, 2003, p.51). It is therefore questionable whether the elimination of the obstacles which have been discovered by this research and the potential optimisation of the overall engine remanufacturing process concords with the objectives of an OEM engine remanufacturer. Case Company A, has begun to outsource parts of their operations shortly after the research was conducted. The research findings therefore rather suggest that engine remanufacturing will prosper with regard to niche markets (e.g. classic car segment). However, it seems to be a non-growing activity for the mass market.

As this research has shown, there seems to be more potential with regard to electronic device remanufacturing. According to the ZVEI (2002), the significance of remanufacturing electronic components in the automotive sector will increase, due to the reasons which have been outlined and discussed in detail in Chapter Seven. Hence, there may be the question to which extent concepts and ideas from 'conventional' forward supply chain management may be applied to electronic device remanufacturing. A similar idea has been posed for commercial returns by Blackburn *et al.* (2004).

[133] Quoted from personal communication (E-Mail) with Tim Durdin, the Managing Director of Wealdstone Engineering Ltd. in Rushden, UK, January 2004. See full interview in Appendix G, Key Interview 4.

The second implication for industry has been discussed in Chapter Nine. It relates to overall changes of product flows in the industry. The question was posed to which extent remanufactured products could fully close the extended loop in the automotive sector. This research has shown that there is (legal) potential to implement a genuinely closed-loop system for remanufacturing in the automotive sector. However, several obstacles with regard to the incorporation of remanufactured products into new cars were outlined, such as the quality requirements for these parts, the unreliability of remanufactured parts supply for the vehicle assembly process, but also the question of liability with regard to recovered products.

This research has shown that the current automotive industry structure is not designed to achieve the 'genuinely', extended closed-loop of remanufactured parts and components. However, there may be future changes in the set-up of automotive distribution and sourcing structures, which may allow the implementation of these ideas. A good case in point is the Micro Factory Retailing approach, which promotes the breakdown of the current industry structure by establishing small car 'microfactories' with an annual capacity of approximately 5,000 units. These Micro Factories would source key components from larger plants, but consider local sourcing for smaller parts (e.g. Nieuwenhuis and Wells, 1999, 2003; Wells and Nieuwenhuis, 2001). This tactic removes the need for dealers, supports a rather local approach to sourcing and would therefore provide lower entry barriers to the industry (Nieuwenhuis and Wells, 2002). As a result, such an approach could be flexible enough to handle the uncertainty which is incorporated within the supply of remanufactured products. It would also support local, low-volume remanufacturers rather than high-volume remanufacturing plants. It could even be considered that remanufacturing is a part of the services microfactories would offer to the customer. However, as also outlined throughout the research, achieving the closure of the extended loop may be more feasible for electronic devices than for passenger car engines.

A second approach of how the findings from the research could be successfully implemented in practice needs to consider other industries. Although the current automotive industry setup is not suitable for closing the extended loop, other industries,

which are less sensitive with regard to safety, supply certainty or quality, could benefit from the research.

The research findings in this dissertation have suggested several requirements for the successful implementation of a closed-loop. The case study on electronic device remanufacturing has demonstrated that products with short life cycles are most suitable for closing the loop. In this way, product obsolescence may be avoided. Moreover, the engine remanufacturing case study raised the issue of eliminating traces of product use (wear-and-tear). Although remanufactured car engines are considered 'as good as new', the product measurements may have changed. This case research has also shown that a successful closed-loop most likely refers to an industry in which safety does not play a major role. A second requirement is that the remanufactured product visually appears to be new. Moreover, the industry in which the closed-loop would be successfully established has to comprise less stringent and more flexible requirements for 'suppliers', in this case remanufacturers, since these face various uncertainties with regard to core supply. Most likely, concepts such as leasing or renting products could support the establishment of these ideas. If these requirements are met, the in-depth results and findings of this research, which have outlined common pitfalls within automotive remanufacturing operations, may support the establishment of a genuinely, extended, closed-loop in other industry sectors.

11.3 Conclusion

This chapter has discussed and summarised the three main contributions made by this research. Firstly, the research has contributed to the parent discipline of closed-loop supply chain management and to the immediate fields of product recovery management and the management of remanufacturing operations. Secondly, a theoretical contribution was made by providing elements for the establishment of a theory for closed-loop supply chain management and additionally by providing new insights for theories from related disciplines, such as industrial ecology. Thirdly, a methodological contribution was achieved by the application of different tools, techniques and perspectives than usually applied within academic research on remanufacturing. In addition, this research has provided a link between the world of product recovery management, which has mostly taken a supply chain management or operations management perspective, and the disciplines of the social sciences. The benefit of such a combined approach is hereby the development of real-world assumptions for scientific research.

On the one hand, this research has applied a broad and holistic perspective by investigating the closed-loop supply chains of two product groups, engines and electronic devices. On the other hand, the research has been characterised by an in-depth investigation of the case study companies and their closed-loop supply chains. As a result, the research has provided many industry-specific insights. Even though the research has been mainly limited to the Original Equipment Manufacturer and only marginally investigated the independent side of the remanufacturing sector, there are various ideas which can be taken into consideration within other industry sectors, for other product recovery operations or with regard to other players in the market. The research findings may therefore be seen as an opportunity for future research to tie in with the many new questions this research on closed-loop supply chain management in the automotive sector has raised.

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