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Product and Process Design for Successful Remanufacturing

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Abstract

Remanufacturing is an industrial process where used products are restored to useful life. This dissertation describes how products can be designed to facilitate the remanufacturing process. It also describes how the remanufacturing processes can be improved to be more efficient.

When comparing remanufacturing with other end-of-life scenarios, it is hard from an environmental perspective to determine which scenario is preferable. This research has shown that remanufacturing is preferable to new manufacturing from a natural resource perspective. With remanufacturing the efforts that initially was used to shape the product part is salvaged. Furthermore, it has been found that it is environmentally and economically beneficial to have products designed for remanufacturing. To avoid obsolescence, the products must be easy to upgrade with new technology in the remanufacturing process.

In this dissertation, a generic remanufacturing process is described with all included steps that are needed to restore the products to useful life. In order to make the remanufacturing process more efficient, the products need to be adapted for the process. Therefore, the preferable products properties facilitating each step in the generic remanufacturing process have been identified. A matrix (RemPro) was created to illustrate the relation between each and every generic remanufacturing step and the preferable product properties.

Remanufacturing case studies have shown that the companies performing remanufacturing often have problems with material flows, use of space and high inventory levels. This is often due to the uncertainties in the quality and the number of cores (used products) that will arrive at the remanufacturing plants. To overcome these problems, the remanufacturers need to achieve a better control over the product's design and use phase, i.e. the life cycle phases that precede the remanufacturing process. This control is best performed by the original equipment manufacturers (OEMs).

Furthermore, it has been found that Swedish manufacturers often have a weak relation between its environmental management systems and product issues, such as design for environment/remanufacturing. Design for environmental/remanufacturing aspects should be a crucial part of the manufacturers environmental management systems (EMSs) as the products stand for much of the material flows at the manufacturing companies. If the external auditors address the manufacturers to have a life cycle perspective on their business the manufacturer would be more likely to adapt the remanufacturing aspects in their environmental management systems.

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Linköping, November 2004

List of publications

Appended Papers

Paper I Sundin E., Jacobsson N. and Björkman M. (2000) Analysis of Service Selling and Design for Remanufacturing, *Proceedings of IEEE International Symposium on Electronics and the Environment (IEEE-00)*, San Francisco, CA, USA, 8-10 May, 2000, pp 272-277.

Paper II Sundin E. (2001) Product Properties Essential for Remanufacturing, *Proceedings of 8th International Seminar on Life Cycle Engineering (LCE-01)*, Sponsored by International Institution for Production Engineering Research (CIRP), Varna, Bulgaria, 18-20 June, pp 171-179.

Paper III Sundin E. (2001) Enhanced Product Design Facilitating Remanufacturing of two Household Appliances - A case study, *Proceedings of International Conference on Engineering Design (ICED-01), Vol. "Design Methods for Performance and Sustainability",* Glasgow, Scotland, The United Kingdom, 21-23 August 2001 pp 645-652.

Paper IV Sundin E. (2001) An Economical and Technical Analysis of a Household Appliance Remanufacturing Process, *Proceedings of EcoDesign-01*, Tokyo, Japan, 12-15 December, pp 536-541.

Paper V Sundin E. and Tyskeng S. (2003) Refurbish or Recycle Household Appliances? An Ecological and Economic study of Electrolux in Sweden, *Proceedings of EcoDesign–03*, Japan, Tokyo, 2003, pp 348-355.

Paper VI Sundin E. and Bras B. (2004) Making Functional Sales Environmentally and Economically Beneficial through Product Remanufacturing. *Accepted for publication in Journal of Cleaner Production.*

Paper VII Ammenberg J. and Sundin E. (2004) Products in Environmental Management Systems: Drivers, Barriers and Experiences. *Accepted for publication in Journal of Cleaner Production.*

Paper VIII Ammenberg J. and Sundin E. (2004) Products in Environmental Management Systems: the Role of Auditors. *Accepted for publication in Journal of Cleaner Production.*

Other Publications

Thesis Sundin E. (2002) *Design for Remanufacturing from a Remanufacturing Process Perspective*, Linköping Studies in Science and Technology, Licentiate Thesis No. 944, LiU-TEK-LIC-2002-17, Department of Mechanical Engineering, Linköpings Universitet, SE-581 83 Linköping, Sweden, ISBN 91-7373-336-9.

Paper Sundin E., Svensson N., McLaren J. and Jackson T. (2002) Material and Energy Flow Analysis of Paper Consumption in the United Kingdom, 1987-2010, *Journal of Industrial Ecology, Volume 5, Number 3*, ISBN 0-262-75075-9, pp 89-105.

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Abbreviations

ABC	Activity Base Costing
CE	Concurrent Engineering
DBT	Design-Build Team
DfA	Design for Assembly
DfD	Design for Disassembly
DfE	Design for the Environment
DfR	Design for Recycling
DfRem	Design for Remanufacturing
DfX	Design for X (where X could be M, A, E, R, D, Rem etc.)
EMS	Environmental Management System
EMAS	Eco-Management and Audit Scheme
EoL	End of Life
EPD	Environmental Product Declaration
GTA	Greater Toronto Area
GWP	Global Warming Potential
IPP	Integrated Product Policy
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
ISO	International Organization for Standardization
ISO14001	ISO-standard for Environmental Management Systems
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MVT	Marginal Value of Time
OEM	Original Equipment Manufacturer
OER	Original Equipment Remanufacturer
PDCA	Plan Do Check Act
PDM	Product Data Management
PDP	Product Development Process
PDT	Product Development Team
POEMS	Product Oriented Environmental Management System
PSS	Product Service System
RoHS	Restricted use of Hazardous Substances
RPA	Rapid Plant Assessment
WCED	World Commission on Environment and Development
WEEE	Waste Electronic and Electrical Equipment
WIP	Work In Progress

1 Introduction

This introductory chapter describe the background of this dissertation research, and more briefly states the driving forces behind the research and the research objective. Furthermore, the relevance of the research and delimitations are described as well as an overview of how the dissertation is structured.

1.1 Sustainable Development

Many natural resources are extracted and used at an increasing rate today, as people all over the world consume materials derived from the crust of the earth. Although new resources are continually discovered, mankind nevertheless needs to start thinking of how to use these resources more wisely and more sustainable. During the last few decades, a spirit of environmental consciousness has grown. In 1987, the World Commission on Environment and Development (WCED) stated the concept of sustainable development as *"a development that meets the needs of the present without compromising the ability of future generations to meet their own need"* (WCED, 1987).

Since the beginning of the industrial revolution, around year 1750, the world population has grown exponentially (see Figure 1 below). Of this population growth, 90 percent has occurred in developing countries (Hart, 1997). The population growth has a strong relationship to the sustainable development and it's focus on not compromising future generations needs. Should people in developing countries exhibit similar consumer patterns, as those in the industrial countries, there would be a huge increase in material consumption. To avoid this scenario, the developed world needs to help the developing countries to leapfrog, at least partially, from pre-industrial to post-industrial systems. A migration towards sustainable development will involve significant and difficult cultural, religious, political and social changes (Graedel and Allenby, 1995).

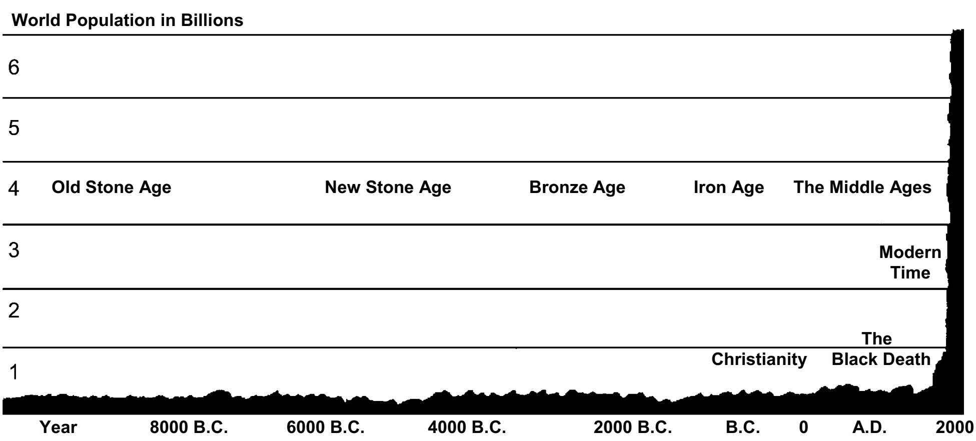


Figure 1. The growth of world population (Kretsloppsdelegationen, 1997).

This dissertation focuses on manufacturing industries and the means for them to strive towards a more sustainable development. By keeping sustainable development in mind, manufacturing companies are forced to satisfy customer needs in a manner that leads to, from a life cycle perspective, less raw material extraction and consumption as well as energy consumption. One of the means to achieve this is to adapt the products for product recovery, where parts of the product or whole products can be reused once again after being used. By doing this, the material flows in today's society are closed into loops instead of the linearity that dominates consumer society today. It is important to view these flows as circular instead of linear.

Sustainable development is sometimes also seen as a goal for industrial ecology, which can be seen as an attempt to create a framework for understanding the impacts of industrial systems on the environment. This framework serves to identify and implement strategies to reduce the environmental impacts of products and processes associated with industrial systems, with the ultimate goal of sustainable development (Garner and Keoleian, 1995).

1.2 Remanufacturing

The remanufacturing industry got a boost during the Second World War when many manufacturing facilities changed from ordinary production to military production, and therefore the products in use were to a large extent remanufactured in order to keep society running. The industry sector that has the most experience in the remanufacturing area is the automotive industry (see e.g. the case study at Cummins OER in Appendix A). However, the concept of remanufacturing has spread during the latest decades to other sectors, such as those dealing with electrical apparatus, toner cartridges, household appliances, machinery, cellular phones etc.

There exist many definitions for remanufacturing (see e.g. Seaver, 1994; Amezquita and Bras, 1996; Bras and Hammond, 1996; Lund, 1996; and APICS, 1998), but most are variations of the same basic idea of product rebuilding. Studying the various definitions the author found a combination of the definitions as useful for the meaning of remanufacturing in this dissertation. In this thesis, remanufacturing is defined as:

> *'Remanufacturing is an industrial process whereby products referred as cores are restored to useful life. During this process the core pass through a number of remanufacturing steps, e.g. inspection, disassembly, part replacement/refurbishment, cleaning, reassembly, and testing to ensure it meets the desired product standards' (based on Seaver, 1994; Amezquita & Bras, 1996; Lund, 1996; APICS, 1998).*

Not all firms engaged in remanufacturing call themselves remanufacturers, however; many in the automobile component remanufacturing sector prefer to use the term 'rebuilding'. Similarly, tire manufacturers call themselves 'retreaders', while laser toner cartridge remanufacturers consider themselves 'rechargers' (Lund, 1996). If the rebuilding of the product is not extensive, i.e., if few parts are to be replaced, either of the terms reconditioning or refurbishing is more suitable. Reconditioning/refurbishing is also used when the product is only remanufactured to its original specifications (Ijomah et al., 1999). Remanufacturing, in any event, is becoming the generic term for the process of restoring discarded products to useful life (Lund, 1996). The remanufacturing process steps, mentioned in the definition above, could be put in a different order, or some steps even omitted, depending on product type, remanufacturing volume, etc. The used/worn out/broken products that enter the remanufacturing process are often called 'cores'. This term will also be used in this dissertation.

The incentives for starting up a remanufacturing business are numerous and dependent on, for example, where the company is situated and which products are to be remanufactured (see e.g. Appendix A). This multitude of driving forces can be shown by the following three examples. Toner cartridge remanufacturers in Canada, for instance, have market demand for remanufactured products as their strongest driving force[1]. Remanufacturers in Sweden, on the other hand, have a steady flow of discarded products since manufacturers have legislative driving forces in the form of responsibilities for taking care of their manufactured products (e.g. Swedish manufacturers have to follow the product take-back laws and thus remanufacturers/recyclers are supplied with end-of-use products[2]). In Japan, on the other hand, a strong driving force for the remanufacturing of single-use cameras is partly of environmental origin[3]. This is due to the fact that used single-use cameras end up at retailers, and need to be taken care of. This is also seen as a good opportunity to improve the environmental image of the remanufacturing company. All of these companies have economic benefits as direct or indirect driving forces for their remanufacturing businesses. The business performance at the individual remanufacturing facilities relies much on the product characteristics and how their remanufacturing system works in relation to their stakeholders.

At manufacturing companies having their own remanufacturing facilities, the remanufacturing volumes of today are normally much lower than the manufacturing volumes[4]. Some manufacturers do not want to remanufacture their products, however, since they claim that they will compete in the same market as the ones that are newly manufactured. Although this statement is true to a degree, other researchers have found that original equipment remanufacturers have much to earn as far as running own remanufacturing businesses (see e.g. Jacobsson, 2000). Other researchers, such as Seitz and Peattie (2004), further confirm several benefits for manufacturers who begin to remanufacture their products, such as a secure supply of spare and replacement parts. Furthermore, for low-volume parts or phased-out products, remanufacturing could speed up the supply of replacement products for customers (Seitz and Peattie, 2004). In some cases, the product also can be monitored during its use, and information gathered could be useful in the remanufacturing process.

According to Furuhjelm (2000), environmental legislation is a driving force for adapting products for the environment. In the aspect of remanufacturing, it is product take-back legislation that concerns the products the most. Examples of Swedish take-back legislation are the laws concerning extended producer responsibility, which means that the manufacturer is responsible for the end-of-life treatment of its products. One aim of this legislation is to achieve a more sustainable society through a higher extent of material

[1] See, e.g. the case studies conducted at 24 Hour Toner Services and MKG Clearprint (Appendix A).
[2] This applies, e.g. to the electronic recycling company MIREC where a pilot case study was conducted.
[3] This applies, e.g. to the case study conducted at FUJI Film (Appendix A).
[4] An exception to this is, seen at BT Industries, who have higher remanufacturing volumes than manufacturing volumes (Munde, 2004).

reuse and recycling. Also, companies will have to learn more about how to use material and manufacture products more efficiently. In the long run, this legislation aims at having products more adapted for the environment through product design (SNV, 2001). As an example, take-back legislation for electrical products was put into force in Sweden on July 1, 2001.

In January 2003, the European Union issued a directive called *Waste Electronic and Electrical Equipment (WEEE)* (EU-WEEE, 2003). The aim with this directive is primarily to prevent the accumulation of waste containing electrical and electronic products, and at the same time promote reuse and material recycling of these kinds of products. Moreover, the directive aims at improve the environmental performance at all stakeholders dealing with these products, e.g. manufacturers, distributors, customers and especially stakeholders dealing with the end-of-life treatment of products. According to this directive, the members of the European Union shall encourage design and manufacturing of electrical and electronic products that facilitates dismantling and recycling, especially reuse and recycling of components and materials from these products. Furthermore, another directive, which became enforceable in 2004, *Restricting the use of Hazardous Substances (RoHS)*, will control the use of hazardous substances during manufacture (Electroversal, 2004). The WEEE and RoHS directives are discussed further in O'Neill (2003) and Stevels (2003). Furthermore, the European Union has developed an Integrated Product Policy (IPP) that aims at reducing the usage of material and the environmental impact of waste (EU-IPP, 2003). The policy is further stated to be a part of the European Union's strategy towards sustainable development by e.g. reducing the environmental impact of products.

1.3 Environmental Management at Manufacturers

The strategies to adopt environmental concerns at manufacturing companies are numerous. A strategy that the European Union is encouraging by issuing the WEEE directive is product remanufacturing and design for remanufacturing. Design for remanufacturing could be seen as a part design for environment (DfE), which is *'an approach to design where all the environmental impacts of a product are considered over the product's life'* (Dewberry and Goggin, 1996). Other DfE strategies than design for remanufacturing is illustrated in Figure 16 and further described in Section 3.3.4. (Brezet and Van Hemel, 1997).

The environmental concerns at manufacturing companies have lately changed focus. From the 1990s and onwards, the focus has shifted from direct impacts from the actual manufacturing facility to a broader perspective looking at what impacts the manufactured product have on the environment. A similar change of focus has been seen at the ISO14001 certified manufacturers in Sweden (Papers VII and VIII). In research, the development of environmental management systems (EMSs) was found to have a strong facility focus, while later the focus shifted to a wider scope of the supply chain (Papers VII and VIII). A wider scope means that the product's entire life cycle is considered, including the use phase and end-of-life scenarios, of which remanufacturing could be one of the scenarios. In order to lower environmental impacts, manufacturers need to integrate their products into their environmental management systems.

A way to integrate environmental considerations at manufacturing companies is to focus on the manufactured product and the development process. Much research has been conducted concerning how to integrate environmental considerations into the product development process i.e. design for environment (DfE), but few researchers have looked into how DfE considerations can be integrated efficiently into manufacturer's environmental management systems (EMSs).

Focus within these issues is put on the companies that hold ISO14001 certificate, but most of the research is also applicable for those companies that are EMAS[5] registered. There are several reasons to look at these aspects. The standardised EMSs should encompass the company environmental impacts, which are connected to flows of material and energy. For the manufacturing industry, these impacts should include products as they contribute to the company's material and energy flows. A common obstacle for this integration often occurs, for example, at large companies where those dealing with DfE issues are not the same people who deal with the EMS issues; designers at the product development department often handle DfE questions, while personnel at the business level of the company often manage EMS questions (SNV, 2003). Furthermore, the environmental effectiveness of EMSs (i.e. improvements in the environment due to the environmental management system) has been debated.

Research has pointed out that DfE is an important way for manufacturing companies to reduce their impact on the environment. At some companies, DfE efforts tend to be short-term projects, e.g. environmental concepts cars, and not a part of the daily product development process. Having a DfE integrated in the EMS could make these DfE projects more integrated into the ordinary product development process. By doing so, continuous improvements and upgraded environmental targets could be reached through product design.

Important in this area, is the knowledge about DfE and EMS at the certified companies and at the firms that are auditing these companies' EMSs in order to achieve a fruitful integration. The ISO14001 auditors are key persons when it comes to what extent product issues are considered in the companies' EMSs. For example, the auditor's knowledge and experience of the DfE area can be crucial for the manufacturers' integration of DfE into their EMS. Remanufacturing and Environmental Management Systems (EMS) are further described in detail in the Chapter 3.

[5] EMAS stands for Eco-Management and Audit Scheme.

1.4 Objective

As the introduction has pointed out, there is a need to explore how to make remanufacturing systems more efficient by changes in product and process design. Furthermore, a need to explore how to integrate environmentally relevant product aspects, such as those that facilitate remanufacturing, into manufacturing companies was elucidated. Hence, the objective of this dissertation is as follows:

To explore how product and process design can contribute to successful remanufacturing and to explore the integration of design for remanufacturing aspects to the environmental management systems of manufacturing companies.

In this dissertation, **successful remanufacturing** means remanufacturing that is technically feasible, has environmental benefits and is economically profitable.

1.4.1 Research Questions

The research objective is rather wide and would require an enormous amount of research in order to be completely fulfilled. To focus the research, this dissertation addresses five research questions. By addressing these research questions, the research objective will be reached. These research questions are treated in the dissertation as described in the following paragraphs.

Since the objective includes finding remanufacturing processes that have environmental benefits, the first research question is stated in order to identify environmental issues related to remanufacturing. The research question deals with the environmental impacts occurring when products are remanufactured. Comparisons to other end-of-life scenarios e.g. material recycling, have to be conducted as well as comparisons to the manufacture of new products. The first research question is:

1. **Is product remanufacturing environmentally preferable in comparison to new product manufacturing and/or material recycling?**

In order to design products for successful remanufacturing, it is crucial to identify the steps that are included in remanufacturing processes. Furthermore, it is of importance to adapt the products intended for remanufacturing for all of the steps in the remanufacturing process. A reason for doing this is to reduce the risks of having products adapted for only some of the steps in the remanufacturing process. Therefore, the second research question is formulated:

2. **What steps are to be included in a generic remanufacturing process?**

When the remanufacturing steps of a generic remanufacturing process have been identified the design for remanufacture aspects must be elucidated. Each step of the generic remanufacturing has to be analysed in order to investigate how remanufacturing could be facilitated by suitable product design. The results of the third research question will provide guidelines for how products could be adapted for the remanufacturing process. With this background in mind, the third research question is:

3. **Which product properties are preferable for the remanufacturing steps?**

In order to achieve technical and economic improvements of remanufacturing processes, the next research question address technical and economic benefits and obstacles. In addition, it further address the efficiency of remanufacturing processes by viewing industrial processes from a lean production perspective. Furthermore, the analysed remanufacturing facilities verify the results from research questions two and three. With this aspect of remanufacturing in mind, the fourth research question is stated:

4. **How can remanufacturing facilities become more efficient?**

The fifth and final research question continues the research based on the results of addressing research question three, where preferable product properties were identified. In order to achieve a better integration of design for remanufacturing aspects into manufacturing companies, the companies' environmental management systems were investigated. As stated in the introduction, product-related issues might not always be considered by the environmental management staff, and thus the fifth research question elucidates this issue further:

5. **How can design for remanufacturing aspects be integrated into manufacturing companies' environmental management systems?**

These five research questions are considered in several research subprojects and they also have a close relation to the appended papers and remanufacturing case studies. As a quick guide to which research papers are related to the research questions stated above, the following table is provided (Table 1):

Table 1. The relationship between the research questions and the appended papers/case studies. The relation with two dots marks the appended papers/case studies that have, a primary focus on a specific research question or questions.

Research Question	I	II	III	IV	V	VI	VII	VIII	Case Studies
1	•				••	•			
2		•		•		••			
3		•	•	•		••			
4									••
5							••	••	

Research questions two and three primarily addressed in the research described in the author's Licentiate thesis (Sundin, 2002). There it was stated that there was a need to further verify the results trough several industrial case studies. These were later performed in the case studies.

1.5 Academic and industrial relevance

Although much research has been carried out in the area of remanufacturing and design for remanufacturing, few researchers have investigated what remanufacturing process steps are to be included in a generic remanufacturing process. Furthermore, few have identified what product properties those are preferable for the remanufacturing steps.

This research project contributes to an increase in knowledge and competence for designing remanufacturing processes within industry. It is also hoped that this research will facilitate the adaptation of industry to environmentally advantageous and efficient remanufacturing, and thus enhance the competitiveness of industry. Companies with knowledge and competence in remanufacturing have the potential for achieving market advantage over their competitors.

Experiences among the analysed remanufacturing companies were exchanged, thus enhancing their knowledge within the remanufacturing area. These experiences from several remanufacturing businesses concern several areas, including process layout, obstacles, bottlenecks, product design adaptation etc., and serve as the foundation of this knowledge. Furthermore, these research results could spread knowledge to those companies that are planning to start or already perform remanufacturing. However, the knowledge should not only be restricted to a few large innovative companies; instead, this research will contribute with the spread of knowledge within the entire industry.

By remanufacturing products, material and energy used in production can be salvaged. In design for environment (DfE), it is common to find most environmental benefits by decreasing the energy use during the product use phase. Since environmental impacts are intimately connected to flows of materials and energy, and the most important flows, at least for manufacturing companies, are closely linked to products (see Ayres, 1994; and Berkhout, 1998), it now seems urgent for environmental management systems to encompass products and product development. Consequently, it was of great interest to illuminate how standardised EMS were related to DfE, e.g. to what extent they encompassed the products and product development procedures.

The exploration of DfE aspects in EMSs will cover an area of research that few have explored. It will also contribute to the debate of whether EMSs really improve a company's impact on the environment (see Ammenberg, 2003). As the number of standardised EMSs in world rises along with the research about them, this research will contribute to a better understanding of what impacts EMSs have and of the role of external auditors.

1.6 Limitations

There are, however, several limitations restraining this research and which cannot be determined in the scope of this research. These limitations are as follows:

- When identifying what product properties were suitable for products aimed for remanufacturing, only two products were analysed. Many of the derived properties were gathered by studying other research findings. Several products could have been analysed to strengthen these results.

- Lack of time restricted the case studies at the remanufacturing facilities to short and rather high level investigations. In depth case studies would have required more time at each remanufacturing facility. The studies in Canada and especially in Japan, for example, did not allow for such in depth studies.

- The number of analysed remanufacturing facilities included in the remanufacturing case study was restricted to six. This was due both to a lack of time and to availability of facilities to study. In any event, it is the opinion here that these six remanufacturing facilities have provided a valuable general picture of the remanufacturing business.

- In most remanufacturing case studies, only the facility manager was interviewed. He/she gave a clear picture of the remanufacturing facility, but if several people had been interviewed some other valuable aspects might also have been discovered.

- Furthermore, in the remanufacturing case studies, ideally the rapid plant assessment (RPA) should be performed by a smaller research team. In this research, one researcher (the author) filled in the RPA in collaboration with the facility manager.

- In the exploration of the auditors' role in the integration of DfE in EMSs, the researchers choose to only interview Swedish auditors. This was a decision of convenience and time saving, since the travel distances were short and sometimes two interviews could be conducted on the same day.

1.7 Delimitations

Delimitations are research restrictions determined by the researcher. This research has much delimitation since the area is wide and needs to focus on a more narrow scope. Therefore, some parts that might be interesting to conduct research on must be excluded. These are the delimitations for this research:

- A delimitation is made over which theoretical areas to base this dissertation research. Therefore, the theoretical foundation include industrial ecology, environmental management systems, product recovery, reverse logistics, product development, design for environment, design for remanufacturing and remanufacturing.

- When conducting the environmental analysis at Electrolux (Paper V) several scenarios could have been analysed in order to achieve a better picture of the environmental concerns of the company's remanufacturing.

- Within this research focus have been put on products that have a certain degree of complexity regarding product structure materials etc. Products such as glass bottles have not been considered.

1.8 Thesis overview

After this introductory chapter, the next chapter (Chapter 2) describes the different methodologies used to address the research questions stated in the objective in Section 1.4. In the third chapter, the theoretical foundation for this research is presented.

Chapter 4 describes the results of this research, which are derived from the eight appended papers and the six remanufacturing case studies. The case study reports are described in Appendix A. Furthermore; Chapter 5 includes a discussion of the results the conclusions made. This chapter also describes what further research needs to be conducted in this area in the future. Following the references in Chapter 6, the appendix contains the remanufacturing case study reports and the appended papers which most of this research dissertation is based on. These are entitled:

- **I. Analysis of Service Selling and Design for Remanufacturing.**
- **II. Product Properties Essential for Remanufacturing.**
- **III. Enhanced Product Design Facilitating Remanufacturing of two Household Appliances - A case study.**
- **IV. An Economical and Technical Analysis of a Household Appliance Remanufacturing Process.**
- **V. Refurbish or Recycle Household Appliances? An Ecological and Economic study of Electrolux in Sweden.**
- **VI. Making Functional Sales Environmentally and Economically Beneficial through Product Remanufacturing.**
- **VII. Products in Environmental Management Systems: Drivers, Barriers and Experiences.**
- **VIII. Products in Environmental Management Systems: the Role of Auditors.**

These will be referred to in the text with the roman letters viewed above. Lastly, the interview questions used for interviewing the facility managers at the remanufacturing companies and the external auditors are appended. The dissertation structure is shown in Figure 2 below.

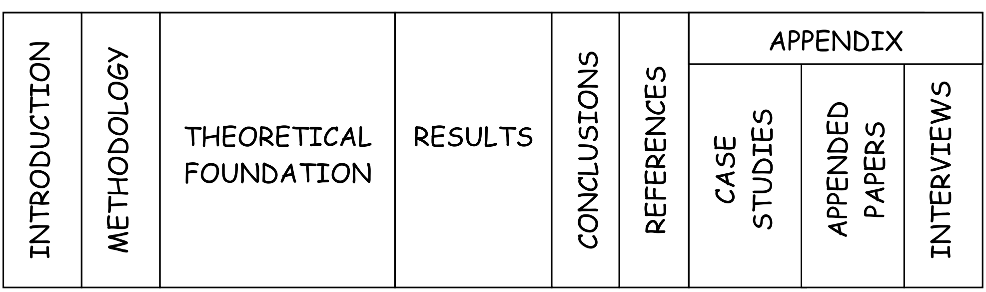


Figure 2. Structure of the dissertation.

2 Research Methodology

In this chapter, the research methodology will be described. At first, the research design is described, followed by which data collections were used and finally the methods for finding answers to the five stated research questions are described.

2.1 Research Design

There are many ways to design research and choose data collection methods considering the selection of research topic, research paradigms, and research questions etc. In the previous chapter the relation between the research objective and the research questions was described. In this chapter the relation between the research questions and the research methods are described.

According to Leady (1997), the scientific method is a means by which insight into the unknown is sought trough a cyclic process, and one that it should be approached in the following steps:

- Clarify the problem that defines the goal of the quest
- Gather the data with the hope of resolving the problem
- Posit a hypothesis both as a logical means of locating the data and as an aid in resolving the problem
- Empirically test the hypothesis by processing and interpreting the data to see whether the interpretation of them will resolve the question that initiated the research

A cyclical and iterative approach can be identified in the author's research starting with the research problem identified for the research included in the licentiate thesis (Sundin, 2002). The problem stated was:

In what manner can products be designed in order to facilitate remanufacturing, from a remanufacturing process perspective?

Following a research cycle, the results from addressing the above stated question was used as a start of a second and a third cycle (no hypothesis posted). The second and third cycle were initiated based on the results from the first cycle together with additional research problems regarding the efficiency of remanufacturing processes and the integration of design for remanufacturing aspects into environmental management. The research cycles for this dissertation are illustrated in Figure 3 below:

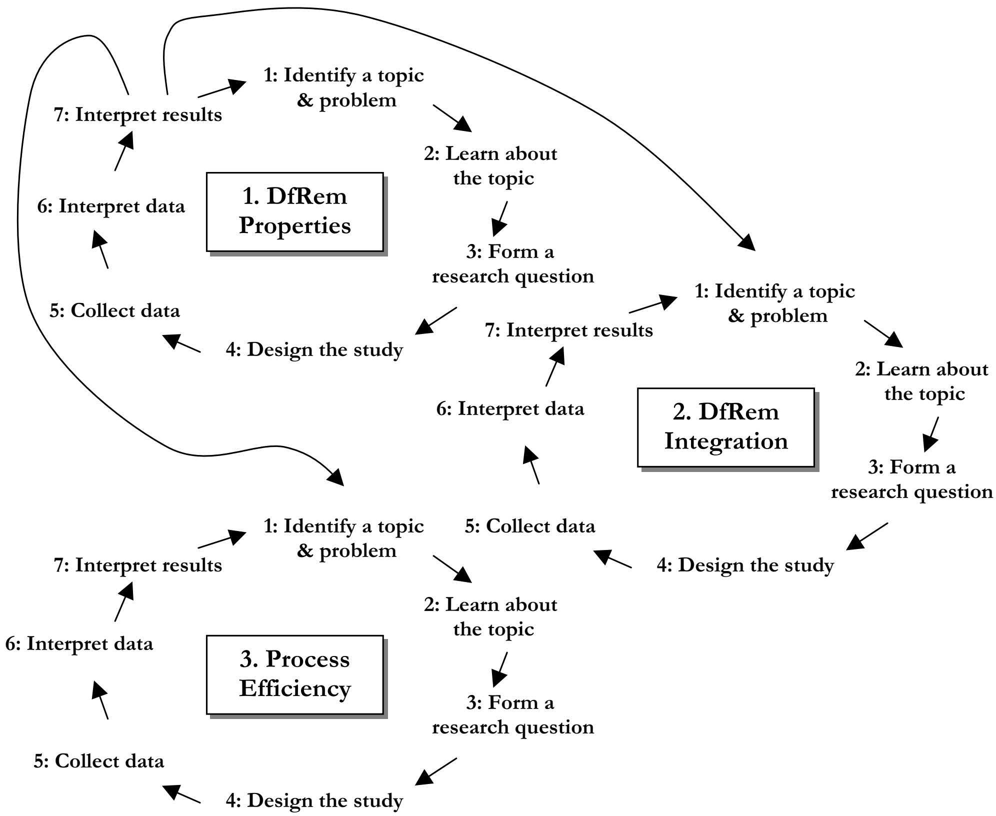


Figure 3. The cyclical nature of this research (adapted from Leedy, 1997)

For the first and third cycle was viewed from an analytical perspective. For the second cycle concerns more a social problem. For social and human problems the researcher has to make a selection between two major research paradigms, qualitative and quantitative research. The paradigms are described by Creswell (1994) as follows:

Qualitative study – an inquiry process of understanding a social or human problem, based on building a complex, holistic picture, formed with words, reporting detailed views of informants, and conducted in a natural setting.

Quantitative study – an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the predictive generalisations of the theory hold true.

Creswell further states selection criteria for the two research paradigms (see Table 1.2 in Creswell, 1994). For the third research cycle, the qualitative research paradigm is selected mainly since the nature of the problem is explorative and needs explorative research in order to be addressed.

Furthermore, when addressing the stated research questions it is of importance to choose a suitable methodology strategy. According to Yin (1994) following forms of research questions are suitable to address by the methodology strategies as Table 2 shows:

Table 2. The relation between research questions and suitable strategies (based on Yin, 1994).

Form of research question	Strategy
How, why	Experiment
Who, what, where, how many, how much	Survey or Archival analysis
How, why	History
How, why, what	Case study

The research question for this dissertation are (again):

1. **Is product remanufacturing environmentally preferable in comparison to new product manufacturing and/or material recycling?**
2. **What steps are to be included in a generic remanufacturing process?**
3. **Which product properties are preferable for the remanufacturing steps?**
4. **How can remanufacturing facilities become more efficient?**
5. **How can design for remanufacturing aspects be integrated into manufacturing companies' environmental management?**

As one can see of the research question's nature, they are mainly of explorative nature starting with the word 'how'. Most of these research questions have chosen to be addressed with a case study perspective according to Table 2. Furthermore, when conducting environmental, technical and economic analyses more specific and suitable data collection have been chosen.

2.2 Data Collection

The data collection for this research has been conducted by multiple means depending on what information was sought. Naturally, the research began with a literature study in the areas explained below in paragraph 2.2.1. Since the start of this research, this literature study has been ongoing. The following paragraphs explain which methods were used for addressing the research questions, in general (2.2.1 – 2.2.4.), as well as the more specific, research questions (2.2.5 – 2.2.9).

2.2.1 Literature Review

A literature review was conducted continuously during this research in order to better understand the research area, as well as to find out what research has been done and what research needs to be done. The following main areas were included in this review:

- Industrial Ecology
- Environmental Management Systems
- Remanufacturing
- Product Development
- Design for Environment
- Design for Remanufacturing

The focus was placed on the area of remanufacturing. Also, these areas have been kept in mind when attending conferences and meeting other researchers.

2.2.2 Interviews

Interviews were the methodology of choice for much of the data collection activities in this research. In the Masters Student projects previously mentioned, interviews were conducted at Electrolux AB. There the students conducted less structured interviews with remanufacturing personnel, followed up by semi-structured interviews with the technical managers of the facility. Also, the facility manager for the remanufacturing plant was interviewed, in order to get all information correct and to keep company secrets intact. The interviews were semi-structured with open questions, i.e. the questions were prepared without specific sequence or answering options (Jacobsen, 1993). Furthermore, the interviewer let the interviewee respond freely, yet without changing the subject, in order to get the most information possible out of these qualitative interviews.

The semi-structured interviews conducted in this research mainly included open questions, which is preferable to use when the answers are very interviewee-dependent (see e.g. Wärneryd et al., 1990). The answers were not easily predicted and categorised. If this were the case, multiple-choice answers could have been used. The questions were structured in a way that comparisons could be performed. According to both Wärneryd et al. (1990) and Yin (1994), it is important to trial run the questions used in semi-structured interviews in order to know that the main aspects are captured. This is especially important when conducting case studies where several cases are to be compared.

Furthermore, semi-structured interviews were used in the remanufacturing case study as well as in the study exploring the auditors' role in the integration of DfE in EMSs. Semi-structured interviews are good to have when making comparisons. In the semi-structured interviews, questions were prepared and presented to the interviewees as objectively as possible. In addition, related questions were asked to further investigate the interviewee's opinions and experiences. These related questions were not prepared in advance, however, since they were dependant on the interviewee's responding answers. The interviews were taped and transcribed before being analysed. This was found to be a good way of conducting the interviews, since some interviewees seemed to have a special opinion at first but when analysing the interview transcription another view was found. The specific developments of interview questions are described in the papers, and the semi-structured interviews for the remanufacturing case studies are illustrated in Appendix C and D, respectively.

2.2.3 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool for calculating environmental impacts of products and processes. LCA is easiest to perform on products that have already been made and for comparing products with each other. LCA can be performed as a part of making the products greener, but can also be used to find out what environmental impacts a product has. It has its origin in chemistry and toxicology. A full LCA includes following four steps (Ryding et al., 1996):

1. Goal definition and scoping
2. Inventory analysis
3. Impact assessment (classification, characterisation, valuation)
4. Improvement assessment

There are some methods used at the inventory step, i.e. Life Cycle Inventory (LCI) methods, providing raw emission data, such as (Simon et al., 1998):

- The Bousted Model
- Euklid
- JEM-LCA
- LCAiT

Many LCA tools have an index as a result, such as the Global Warming Potential (GWP), which makes it easy to compare with other products or processes. Few of them continue with an evaluation (Simon et al., 1998). LCA has sometimes received criticism for being time and cost consuming. Further, LCA software tools are often stand-alone applications with no connection to other tools or product data management (PDM) (Schlüter, 2001). To deal with this criticism, abridged LCA methods have been developed. These methods are not as detailed as a full LCA and can therefore be conducted in shorter time with less effort. Not as much data is needed as in a full LCA and methods become more qualitative. More background knowledge is sometimes required and the results are not as reliable in comparison with a full LCA. Results of from both types of LCA tools can be similar though an abridged LCA is less time consuming.

2.2.4 ABC – methodology

Some economic analyses in this dissertation research were conducted by using an Activity Based Costing (ABC) method. Using ABC, the use of resources are more representative then when using traditional economic calculation methods, since the cost allocations are based on the direct cost drivers inherent in each of the work activities that make up the organizational structure. ABC applies resource use directly to the output products and services based on the actual work activities of the process that produces the output with limited arbitrary allocations of indirect or overhead costs (ABC Guidebook, 2003).

The traditional cost accounting methodology can create a significant difference in output costs because of the manner in which overhead costs are allocated to output rather than traced to output. The method of applying overhead costs directly to the output can overstate or understate the true cost when a full internal review is done on how the costs are incurred. This difference in distribution can skew the ultimate price of the output and lead to poor management decisions. Activity-based costing gives a more accurate picture of output costs by tracing overhead cost through the activities that are actually used to produce the output, rather than straight allocation (ABC Guidebook, 2003).

ABC is not, however, necessarily appropriate for all businesses. In some cases, especially where a product with low complexity is produced, it may be appropriate to use more traditional methods of cost allocation. Moreover, an ABC system is usually more complex than other accounting systems. In a company with a large number of activities and different cost drivers, the allocation of indirect costs can be unforeseeable. The implementation of such a system consumes both time and resources. It is, therefore, important to compare the benefits for the company with the costs of implementation.

The ABC method is appropriate for remanufacturing processes when the amount of activities is limited and the overhead costs are high. It has been shown earlier in remanufacturing research that this method is preferable (see e.g. Emblemsvåg and Bras, 2001)[6]. The costs that accrue during the process are divided into direct and indirect costs, with direct labour and direct material costs are included in direct costs. An ABC accounting method was used to allocate the indirect costs.

This method seemed to be a good choice to fulfil the aims of this analysis. Traditional calculation methods often simplify the cost relations, since the indirect costs usually are distributed with a single additional charge. Having an activity-based calculation in mind, the costs are related to the real origin. ABC distributes the costs on the resources that actually use the resource. A goal for this method is to treat all costs as direct costs instead of indirect. The largest differences in calculation between ABC and traditional calculations occur for companies that have a high percentage of indirect costs. Of course, there are some disadvantages of using this method. For example, the method can get complex when there are many activities involved in a company, and also when costs for the research and development of new products is not accounted for. The ABC-method is fully described in Kaplan and Cooper (1998).

2.2.5 Rapid Plant Assessment (RPA)

This method was developed by E. Goodson at the University of Michigan, Ann Arbour, USA, in the late 1990s. The Rapid Plant Assessment (RPA) is a tool which can be effectively used for finding where in manufacturing processes facilities can be improved. Goodson got his inspiration from Japanese managers who when visiting American facilities and analysing them quickly from a lean production perspective. Since 1998, Goodson carried out the analysis of over 400 manufacturing plants analysed with the tool. All these studies have been kept in a database (Goodson, 2002).

At the heart of the RPA process are two assessment tools for teams performing plant tours. The RPA rating sheet (see examples in the case study reports in appendix A) presents 11 categories for assessing the leanness of a plant, and the RPA questionnaire provides 20 associated yes-or-no questions to determine if the plant uses best practises in these categories. Following a tour, team members will capture their observations in work sheets like the two shown in the case study reports (Goodson, 2002).

[6]Other case studies of ABC-calculations at remanufacturing facilities are described in Kerr and Ryan (2001) and Emblemsvåg and Bras (2001).

During a tour, team members observe all aspects of a plant's environment, talk with the workforce and managers, and look for evidence that the plant adheres to best practises. It is important that team members not take notes during a tour, according to Goodson, because note taking distracts from picking up visual cues and impedes communication with employees on the plant floor. Instead, each member of the team is assigned primary responsibility for a few categories, and the team should meet immediately after the tour to share impressions and fill out the work sheets (Goodson, 2002). The categories are:

1. Customer Satisfaction
2. Safety, Environment and Order
3. Visual Management System
4. Scheduling System
5. Use of Space, Movement of Materials and Product Line Flow
6. Levels of Inventory and Work in Process
7. Teamwork and Motivation
8. Condition and Maintenance of Equipment and Tools
9. Management of Complexity and Variability
10. Supply Chain Integration
11. Commitment to Quality

The team should use both the RPA rating sheet and the questionnaire to rate leanness. Each of the categories should be rated on a scale from 'poor' (1) to 'excellent' (9) to 'best in class' (11). The questionnaire is completed at the same time. The plants total score on the rating sheet and the number of yeses on the questionnaire gives a fairly accurate assessment of a plant's efficiency. The assessments on the rating sheet may be particularly useful because the categories highlight broad areas of strength and weakness. Categories with low ratings are instantly visible opportunities for improvement, and should be the first steps on a company's journey to leanness (Goodson, 2002).

2.2.6 Case Study Methodology

In order to achieve a solid scientific structure for data collection in these remanufacturing facility case studies, a case study methodology provided by Yin (1994) was used. Case study methodology relies on qualitative evidence and is a way of investigating an empirical topic by following a set of pre-specified procedures. When performing case studies, it is important to prepare the actual case studies. According to Yin, this includes;

- desired skills
- training
- case study protocol
- pilot case study

The skills required for collecting case study data are much more demanding than those for experiments and surveys, according to Yin. In order to increase reliability for the case studies, a case study protocol is written. This is, according to Yin (1994), especially important when conducting multiple case studies. The protocol for these case studies is described in the following section.

Case Study Protocol

The methodology approach provided in his book suggests that the case study protocol should include following parts:

I. An overview of the case study project (objectives, issues, literature review),
II. Field procedures,
III. Case study questions, and
IV. A guide for the case study report.

The guide for the case studies and the case study reports are shown in Appendix A. After making all case study reports, a cross case analysis was written (see Section 4.4.7.).

2.2.7 Master of Science Student Projects

In some research subprojects, students in master programmes have conducting supporting research. These subprojects have been stated and developed by the author. The Master of Science students have conducted their subprojects under the supervision of the author. These four subprojects have been ongoing for five months, and included two to four students per project. These entire student projects are described in reports (Eriksson et al., 2000; Orrby and Svensson, 2000; Westerberg and Grotkamp, 2001; and Hildén et al., 2003) and further condensed with some other theories and data into the three appended Papers III, IV and V, as mentioned above.

2.2.8 Methods for the first research question

RQ1: Is product remanufacturing environmentally preferable in comparison to new product manufacturing and/or material recycling?

This research question was addressed through studying other researchers results and performing an environmental and economic analysis of the refurbishment of household appliances at Electrolux AB[7]. The literature study included research from the remanufacturing of various products and as well as previously performed calculations made by Electrolux.

Furthermore, a comparison was conducted, by four master students, between two scenarios concerning the end-of-life scenario for household appliances at Electrolux, Sweden. In order to make these scenarios as comparable as possible, similar system boundaries for the different analyses were used. The scenarios start at when and where a household appliance has broken down in Sweden. Repairmen at Electrolux Service then have three attempts to repair the products at the customer. After these three attempts, the products are transported to the local Electrolux Service centre, where the two scenarios begin. Most of the data for the analyses was gathered through literature, Internet and communication with employees at Electrolux. Other companies were also contacted in order to acquire data for transportation and recycling.

[7] The actual investigation was planned and supervised by the author and Sara Tyskeng, while it was performed by four students as a student project at Linköping University spring 2003.

These scenarios are described in detail in Hildén et al. (2003) and Paper V. An important part when making comparisons like these is to clearly define which system boundaries were used.

The environmental effects for the different scenarios were compared using a life cycle perspective. The tool for conducting the inventory part of the assessment was the software called LCAiT[8]. Previously conducted LCAs and Environmental Product Declarations (EPDs) by Electrolux were used to gather the right information about the products. The functional unit used for the two products in both scenarios were one refrigerator (Electrolux ERB3105) and one washing machine (AEG Lavamat 72330W), respectively (see Figure 4).

Figure 4. Functional units for the environmental analysis (EPD-R, 2003 and EPD-WM, 2003).

The data for the cost analysis in the remanufacturing scenario was collected from Electrolux executives during visits to the Motala facility, and by using appropriate assumptions. A former project report (Westerberg and Grotkamp, 2001) was also used as a source for cost information. The costs of material recycling at Electrolux are traced in the scenario covering material recycling. The goal is to compare recycling costs with refurbishment costs. That is why some costs that would accrue in both cases are left out from the comparison in order to make the calculation easier to understand and carry out. The economic analysis was conducted by using an Activity Based Costing (ABC) method.

2.2.9 Methods used for the second research question

RQ2: What steps are to be included in a generic remanufacturing process?

In order to solve the second research question, an extensive literature study was conducted within the areas of remanufacturing. Remanufacturing plants for household appliances and automotive parts were the focus of industrial case studies to determine how well the theory in this area is coupled to reality, complemented with other remanufacturing processes described in the literature (see Paper VI).

Many experiences leading towards identifying a generic remanufacturing process were taken from working with the remanufacturing facility in Motala, Sweden managed by Electrolux AB. The experiences were collected through numerous visits and informal interviews with the facility managers and through master student projects. The remanufacturing process in Motala was analysed through interviews with remanufacturing personnel and remanufacturing process monitoring.

When the generic remanufacturing process was identified, the case studies performed at several remanufacturing facilities were used to verify the identified process.

[8] The software was developed by CIT-Ekologik at Chalmers Industriteknik, a research organisation at Chalmers University of Technology, Sweden.

2.2.10 Methods used for the third research question

RQ3: Which product properties are preferable for the remanufacturing steps?

The making of the RemPro matrix is based on the steps found in the generic remanufacturing process. Therefore, the methodology for the projects resulting in Papers II, III, IV and VI is also applicable for this research question. Much effort was put into studying what other researchers found preferable for the specific steps in the remanufacturing process, as described in Paper VI. The literature study was complemented by three master student projects. In the first, two household appliances were analysed through a remanufacturing perspective (Eriksson et al., 2000; Paper III), while in the other a remanufacturing process was analysed three times by three sets of students with different project goals (Orrby and Svensson, 2000; Westerberg and Grotkamp, 2001; Hildén et al., 2003; and Paper IV).

Product Analysis

In the beginning of the first student subproject, a literature review of relevant subjects was made. Subjects studied were, for example, disassembly, DfE, assembly technology, hygienic design, tools for DfE and joining methods. With this theoretical background, two household appliances were analysed (a washing machine and a refrigerator). The analysis included much attention to disassembly and reassembly in order to discover obstacles for remanufacturing and to thoroughly understand the product design structure. The product analyses were performed at a university laboratory with ordinary work tools, e.g. screwdrivers and wrenches. Visits to the remanufacturing plant in Motala were made to ensure that the working conditions were the same and to conduct interviews with the remanufacturing personnel. Feedback on the design changes was given through an interview of the remanufacturing production manager, with consideration to economical and mechanical constraints to the proposed design changes.

Process Analysis

Three other master student projects were performed at a remanufacturing facility owned by Electrolux AB, situated in Motala, Sweden.

The first project (Orrby and Svensson, 2000) included a technical analysis of the remanufacturing process, which was conducted to find out technical constraints and bottlenecks in the process. The analysis was carried out on two levels: one that overviewed the whole process, and another that looked deeper into the specific remanufacturing steps.

The second student project (Westerberg and Grotkamp, 2001) aimed at mapping the cost relations on a more detailed level. In order to identify what costs were associated with the remanufacturing process, an economic analysis was conducted. The costs of the different remanufacturing steps were calculated and compared to the total cost of the entire remanufacturing process. By doing this, Electrolux could easier understand what process steps were needed to improve for different products in order to lower the costs of remanufacturing. The method used for this analysis was Activity Based Costing (ABC).

The third student project (Hildén et al., 2003) was also using the ABC-method, but with the aim of comparing the scenarios of remanufacturing and recycling household appliances at Electrolux AB.

2.2.11 Methods for the fourth research question

RQ4: How can remanufacturing facilities become more efficient?

The methodology for the case studies was a combination of existing analysing methods such as semi-structured interviews and the Rapid Plant Assessment (RPA). The investigations at different plants were conducted using the same method, in order to enable a good comparison. Several remanufacturing facilities were analysed from both economic and technical perspectives. The comparisons between the facilities concerned, for example, the choice of process, degree of flexibility, throughput time, bottlenecks and inventory levels.

Research Design

Until the year 2002, the author had conducted research in close cooperation with Electrolux AB, and mainly with the company's remanufacturing facility for household appliances in Motala, Sweden. To draw more general conclusions about analyses in the remanufacturing area, more facilities and other products needed to be explored. In Canada, case studies focused on three remanufacturers, one small and two larger firms. The first two companies explored were '24 Hour Toner Services' and 'MKG Clearprint' both of which remanufacture toner cartridges. The third case study company in Canada, 'Cummins OER', was along with 'MKG Clearprint' much larger than '24 Hour Toner Services'. 'Cummins Original Equipment Remanufacturing' (Cummins OER) remanufactures gasoline engines for corporations such as Daimler-Chrysler, Volkswagen, Audi and Mitsubishi (Cummins, 2002). All three of these remanufacturers have been in contact with researchers from the Life Cycle Design Laboratory at University of Toronto, where researchers had previously worked with these companies in the analysis of remanufactured products (see e.g. Williams and Shu, 2000). Later, a single-use camera manufacturer/remanufacturer in Japan was studied. This company has a big advantage of having a high percentage of product returns to the photo shops around Japan. Lastly, two companies in Sweden were studied which remanufactures household appliances (Electrolux AB) and disassemble heavy trucks (Scania CV AB).

As described in Section 2.2.5., the case study methodology proposed by Yin (1994) was used. In the next paragraphs the content of the case study protocol is described including:

I. An overview of the case study project (objectives, issues, literature review),
II. Field procedures,
III. Case study questions, and
IV. A guide for the case study report.

I. Overview of the case study project

Remanufacturing facilities are of different nature, for example, depending on what products and at which volumes they are being remanufactured at. In addition, what kind of culture and legislation also affect the drivers and barriers for remanufacturing. This case study project analysed the economic and technical perspectives several remanufacturing facilities from all around the world.

The case study project started off in Canada at remanufacturers dealing with e.g. toner cartridges and gasoline engines. The Canadian part of the case study had complementary studies in Sweden and Japan with analyses of the remanufacture of household appliances, single-use cameras and heavy trucks.

The aim for the case study was to analyse remanufacturing facilities in order to find technical and economic similarities and differences, for example, concerning flexibility, layout, process choice, throughput time, bottlenecks and costs. The analyses were conducted on site, and the data that was collected concerned the remanufacturing facility's:

- product type
- type of reverse logistics
- volumes
- throughput time
- flexibility
- layout
- process choice
- etc.

In order to make these analyses, a literature study was conducted in the areas of:

- Remanufacturing
- Product Recovery
- Lean Manufacturing
- Activity Base Costing

II. Field procedures

Firstly, a description of the case study was sent out to potential remanufacturing companies. Awaiting the answers, a pilot study was conducted at MIREC recyclers in Tåby, Sweden. Since contact already was established with this facility, it was convenient to use it for a pilot study to find out if there were any changes needed in the case study protocol.

Since, information and data from the facilities was to be as accurate as possible, several data collection methods were to be used. The case study procedure had following sequence:

Part 1: Conduct a "Read-a-plant" analysis
Part 2: Mapping of the remanufacturing process
Part 3: Interview the facility manager
Part 4: Interview some of the remanufacturing personnel
Part 5: Evaluate with Rapid Plant Assessment (RPA)[9]
Part 6: Read reports and brochures about the company

[9] The RPA was described in Section 2.2.5.

Part 7: Transcribe interviews
Part 8: Achieve verification from company
Part 9: Analyse the results and reflect

Finally, the case study reports were written.

III. Case Study Questions

There were various types of questions that these case studies addressed. Some of them were very detailed, and therefore most suitable to be answered in interviews with the facility manager. Other, more overall case study questions were best answered through the different data collection methods. These were as follows:

- Obstacles in the remanufacturing process
- Bottlenecks in the remanufacturing process
- Process layout including remanufacturing steps
- Process organisation
- Handling of product information
- Reverse Logistics

The following table shows how the questions above were answered through the different data collection methods (Table 3).

Table 3. Relationships between case study questions and data collection methods.

	Obstacles in the process	Bottlenecks in the process	Process layout (Reman. steps)	Process organisation	Reverse Logistics
"Read a plant"	x	x		x	
Process mapping			x		x
Manager Interview	x	x	x	x	x
Personnel Interview	x	x		x	
Observations	x	x	x		
Other Methods	x		x	x	x

Having several data collection methods to find answers to the same case study questions are with the term ‘triangulation’.

Furthermore, the guide for the case study reports and the case study reports are described in Appendix A. The results and cross case analysis is described in Section 4.4.

2.2.12 Methods used for the fifth research question

RQ5: How can design for remanufacturing aspects be integrated into manufacturing companies’ environmental management systems?

The fifth research question looked at how standardised EMSs were related to Design for the Environment (DfE), i.e. to what extent they encompass the products and product development procedures. The project members[10] initiated a literature study, which is described in Paper VII. To deal with these issues, the paper aimed to elucidate the following subtopics:

- What are the incentives to strengthen the connection between EMS and DfE?
- How can DfE activities be incorporated into standardised EMS?
- How common is it that EMS encompasses DfE activities?
- What are the experiences from projects where EMS and DfE activities have been integrated?
- Which important factors influence to what extent EMS and DfE activities are integrated and/or the outcome of such integration?

For the second part of this issue (Paper VIII), the viewpoint of external auditors was targeted. The study was conducted through semi-structured interviews with nine auditors, one from each of the nine Swedish certification bodies. These firms cover an absolutely dominant part of the EMS certification in Sweden, but there are also some foreign companies in this market. In most cases, the selected auditors[11] represented the certification body in a joint group, where common topics of interest to the certification bodies are discussed and common practices are developed, e.g. issues concerning interpretation of central requirements of ISO14001.

To be able to compare the answers without steering the interviewees too much, semi-structured interviews were used (see Ries et al., 1999). This means that some main questions, to be presented and theoretically motivated later in this section, were prepared in advance and directed at all auditors. These prepared questions served as 'signposts' to point out the direction for the following conversation. In addition, many related questions were asked to further investigate the opinion and practice of the interviewees. These questions were not prepared in advance, but depended on the answers given.

For the interviewer to be able to listen carefully, focus on the answers and formulate appropriately related questions, the interviews were recorded on tape. This may have resulted in some tension for the interviewees. However, every interviewed auditor was promised full anonymity, both individually and concerning his or her company and the audited firms. This, hopefully, lessened any anxiety. An absolute majority of the auditors appeared to be relaxed during these interviews. It was emphasised that the auditors should focus on manufacturing companies. It was also stressed that by 'products', the interviewers were referring to the physical products produced by the manufacturing firms focused on, and by 'product development', referred to the formal organisational procedures and processes which were intended to steer the product design and production.

[10] Jonas Ammenberg and the author.

[11] The selection of auditors from this special group was a conscious choice made by the auditing firms in order to get successful auditors with extensive manufacturing experience that was search for.

After all interviews had been conducted, the recorded answers were analysed. First, they were transcribed and then a process to summarize the answers began. Next, the interview material was characterized and classified - a process involving interpretation and a search for keywords. This process was designed to extract the core points of the answers and to divide them into several more or less separate groups. In other words, they were transformed to fit a more quantitative analysis.

During the entire interview and interpretation process, subjectivity is a problem (Kvale, 1996). Being aware of that fact, the consequences of this problem have hopefully been restricted. For example, the introductions to each interview and the questions have been formulated in such a way as to avoid leading the interviewees. Furthermore, the questions were organised according to level of detail. Within each area of interest, the respondents were first asked comprehensive questions, followed by questions on a more detailed level (see the interview questions in Appendix C). As a result, the risk of leading the respondents has been reduced.

During the phase of interpretation, characterization and classification of the answers, the authors tried to understand the central opinions of the interviewees and thereby to summarize the answers as correctly as possible, which of course is a difficult research question and a weakness of the methodology. However, the standardised terminology concerning EMS makes it easier to communicate on these issues. In addition, the interviewers to some extent summarized their impressions during the interviews and asked the respondents if they had been correctly understood, which facilitated the interpretation process. Naturally, what was selected in this process and presented as results depended on the aim of the study.

3 Theoretical Foundation

This chapter explains the theory of importance for this research. It is the theoretical basis for the research conducted in this thesis. The research area of remanufacturing is described in itself and with the perspectives of product development and industrial ecology.

3.1 Mapping the research area

Setting the theoretical foundation for this research was not an easy task, since there are many areas related to the research topic. Remanufacturing has the main focus of this research and therefore also the focus in the theoretical foundation. The concept of remanufacturing is in this dissertation seen from many perspectives. Figure 5 illustrates the areas of theoretical interest in this dissertation. The picture is not complete but it contains the most important areas concerning this remanufacturing research.

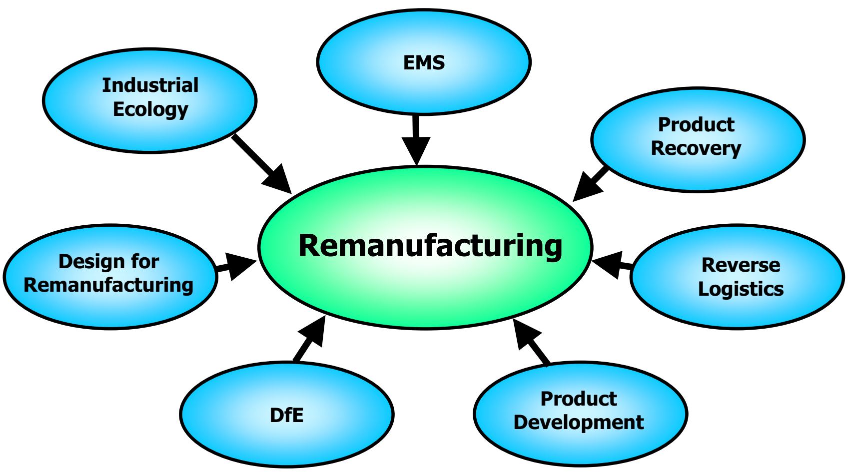


Figure 5. Theoretical areas which concerns the concept of remanufacturing.

All of these areas of theory are described in the following sections with its relation to remanufacturing. The following sections start off by describing the remanufacturing concept and continue by describing it from the perspectives of product development industrial ecology including the areas shown in Figure 5.

3.2 Remanufacturing

The remanufacture of automotive engines, gearboxes, and other components flourished in the situation of material scarcity during the Second World War. Remanufacturing began with small independent companies providing cheap replacement parts. Vehicle manufacturers ignored this business opportunity for many years, viewing it as a 'dirty' part of the industry that lacked the glamour of new car production and marketing. In the USA, although remanufacturing is a major business, Original Equipment Manufacturers (OEMs) still remain relatively disengaged and account for less than five percent of total remanufacturing activity (Guide Jr., 2000). In Europe, OEMs have recently discovered the aftermarket potential for remanufactured products, and many are now involved (Seitz and Peattie, 2004).

3.2.1 The concept of Remanufacturing

A remanufactured product is often the term of a worn-out/broken/used product that has been restored to its original specifications or has been modernised and upgraded to new specifications. Hence, remanufacturing not only promotes the multiple reuse of materials, but it also allows for the steady upgrading of quality and functions of products, and does this without the need to manufacture completely new products and throw away used ones. The used/worn-out/broken products that arrive into the remanufacturing process are often called 'cores', see e.g. Lund (1996) and Smith and Keoleian (2004). Hence, this term 'core' will also be used in this dissertation thesis.

There exist many definitions for remanufacturing (see e.g. Seaver, 1994; Amezquita and Bras, 1996; Bras and Hammond, 1996; Lund, 1996; APICS, 1998), but most are variations of the same basic idea of product rebuilding. Studying the various definitions the author found a combination of the definitions set by some of these authors as useful for this dissertation, in which, remanufacturing is defined as follows:

> *'Remanufacturing is an industrial process whereby products referred as cores are restored to useful life. During this process the core pass through a number of remanufacturing steps, e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly, and testing to ensure it meets the desired product standards' (based on Seaver, 1994; Lund, 1996; Amezquita & Bras, 1996; APICS, 1998).*

Not all firms engaged in remanufacturing call themselves remanufacturers, however; many in the automobile component remanufacturing sector prefer to use the term 'rebuilding'. Similarly, tire manufacturers call themselves 'retreaders', while laser toner cartridge remanufacturers consider themselves 'rechargers' (Lund, 1996). If the rebuilding of the product is not extensive, i.e., if few parts are to be replaced, either of the terms *reconditioning* or *refurbishing* may be more suitable. Reconditioning/refurbishing is often also used when the product is only remanufactured to its original specifications (Ijomah et al., 1999). Remanufacturing, in any event, is becoming the generic term for the process of restoring discarded products to useful life (Lund, 1996). The remanufacturing process steps, mentioned in the definition above, could be put in a different order, or some steps even omitted, depending on product type, remanufacturing volume, etc. The following figure (Figure 6) illustrates one way of structuring the remanufacturing steps.

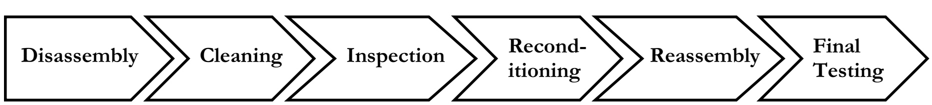


Figure 6. An example of a generic remanufacturing process, based on the five key steps described in Steinhilper (1998).

Bras and Hammond (1996) have found similar generic remanufacturing steps through literature studies and surveys. The issue of what steps are to be included in a generic remanufacturing process is further discussed in Section 4.2. In an attempt to develop a remanufacturing metric, Bras and Hammond (1996) aggregated the steps into the following categories:

- Cleaning
- Damage correction (repair, refurbishment and replacement)
- Quality assurance (testing and inspection)
- Part interfacing (disassembly and assembly)

According to experiences of study visits by the author, remanufacturing companies choose different sequences of executing the remanufacturing steps. For example, the cores could either be disassembled followed by inspection (e.g. error detection) or the inspection could be the first step, without first being disassembled. In research, the remanufacturing process often is described with the inspection step taking place after the cleaning and disassembling steps. This, however, is not efficient if the product has fatal errors, which make it less meaningful to remanufacture. In addition, the product is easier to inspect when cleaned, and some products might be impossible to inspect if not cleaned. Hence, it is wise to choose a sequence that enables efficient remanufacture, as well as a strategy that takes into account the type of product being remanufactured.

3.2.2 Actors in Remanufacturing

There are different types of companies that perform remanufacturing. These companies can be divided according to their relationship to the product manufacturer, i.e. the Original Equipment Manufacturer (OEM). These following three categories of remanufacturers were also described by Lund (1983) and Jacobsson (2000):

Original Equipment Remanufacturers - Firstly, there are certain OEMs which remanufacture their own products; these companies are also called Original Equipment Remanufacturers[12] (OERs). In this case, it is the OEM/OER who remanufactures its own products arriving from service centres, trade-ins from retailers or end-of-lease contracts. For these OEMs/OERs, the remanufacture of products is profitable, and they can, as in the previous case, offer their customers a wider price range of products. Furthermore, OEMs/OERs have all the needed information concerning product design, availability of spare parts and service knowledge. The remanufacturing process could be integrated with the ordinary manufacturing process or be separated from it. Also, the parts from the remanufactured products could be used in manufacturing, or the products could be entirely remanufactured. An example of this kind of company is FUJI Film, which remanufactures its single-use cameras in Japan at the same facility as it produces these cameras. The FUJI Film case is further described in Appendix A.

Contracted remanufacturers - Secondly, there are remanufacturing companies that are contracted to remanufacture products on behalf of other companies. This means that the

[12] An OER is in this dissertation defined as the business unit in the OEM that performs the remanufacturing.

OEM normally owns the products, but does not need to perform the actual remanufacturing of them. Still, the OEMs have their products remanufactured and can offer them to their customers once again for a lower price. For the remanufacturer, there is likely to be a fairly consistent stream of business with fewer working capital requirements (e.g. work in progress) and risks, and the company can expect to obtain assistance from the OEM in terms of replacement parts, design and testing specifications, and even tooling (Lund, 1983). An example of this kind of remanufacturer is Our-Way Inc., which remanufactures refrigeration compressors in Atlanta, USA (Lund, 1983).

Independent remanufacturers - Thirdly, there are many independent remanufacturers who remanufacture products with little contact with the OEM, and who need to buy or collect cores for their process. Sometimes, these companies are paid by the last owner or distributor to pick up discarded products (Jacobsson, 2000). These independent remanufacturers also often need to buy spare parts for their products that are to be remanufactured. The typical independent remanufacturer is a private corporation with ownership closely held (Lund, 1983). Lund further states that this type of operation is an integrated one, in that it purchases cores, remanufactures them and markets them under its own name or for the private labels of others. Generally, exchange of experience between these remanufacturers concerning reprocessing to the OEM is minimal (Jacobsson, 2000). Furthermore, Hammond et al. (1998) states that it is not likely that the relationship between independent remanufacturers and OEMs will grow in the future. An example of this kind of remanufacturer is 24 Hour Toner Services, which remanufactures toner cartridges in Toronto, and which is further described in Appendix A.

All remanufacturing firms, however, cannot be neatly placed into the categories above; some companies display a mix of these remanufacturing types. For example, an independent remanufacturer could have some of its products contracted with OEMs. Another example from Sweden is the household appliance manufacturer Electrolux AB, which remanufactures its own household appliances arriving from its service centres while it also is contracted to a Danish leasing company called L'Easy to refurbish that company's appliances.

3.2.3 Benefits of Remanufacturing

For the three types of remanufacturing companies, there are different prerequisites to achieve profit and environmental savings. Most of these are valid for the OEM remanufacturers. For example, Jacobsson (2000) has listed the following potential advantages for OEM to perform remanufacturing:

- The OEM produced the product and is the only organisation to have full access to a complete set of specifications on the product's design and content. Consequently, the OEM also has the potential to make informed decisions about its expected durability and reliability. This kind of information prepares the OER for dealing with the product in the remanufacturing process. Disassembly is facilitated as well as the decision on what can be recovered from the product and how it may be modified. Also, decisions on the level of required maintenance are facilitated by access to this type of data.

- The OEM sold the product and has access to an established network for distribution of the original product. Consequently, the OER also has access to a network for distribution of the remanufactured product as well as a network for collection of discarded products. In addition, the OER is in a better situation to build a relationship with the end customer to provide the remanufacturing operation with information on what end-of-life products to expect, when and in what quantities.

- The OEM also has an established supplier network for its manufacturing operations. This provides the remanufacturing operations with a supply of original parts, which would be difficult to obtain from other parties. Independent remanufacturers seldom have this opportunity, and instead must rely on replicas and/or purchases from the OEM.

Furthermore, by using the supply chain network, the following advantages were also highlighted by Jacobsson (2000):

- Knowledge of the consumers provides the OEM with user patterns, which, in turn, are valuable in evaluating the remaining values in the discarded product.

- Detailed information of the consumers and the market for the original product also provide the OEM with advantages in the marketing of the product. First of all, the OEM can estimate the size of the market and remanufacture products according to estimated demand. Secondly, this kind of information provides the OEM with an excellent situation to evaluate the requirements from the customers and which market segments may be interested in the remanufactured products.

- With regard to marketing, the OEM also has the advantage of using its reputation for producing high quality products in the process of convincing the customer of the reliability of the remanufactured products.

- By having the equipment, competence and infrastructure for manufacturing in place, the OEM already has a system that can be reversed. It also reduces the need for investments for the remanufacturing operations.

- The OEM generally produces higher quantities allowing for investments in more advanced production/remanufacturing equipment.

- The OEM is also generally better equipped to earn profit from remanufacturing, as recovered parts can be used in the manufacturing process, providing a higher return than if the parts were to be sold.

These should be seen as potential advantages, which many OEM remanufacturers do not take advantage of. Another potential benefit is that designers could achieve knowledge of how well their designs perform in the use and end-of-life phases, and new designs could be developed to avoid possible problems in use and remanufacture in the future. This type of design, known as Design for Remanufacturing (DfRem), is further described in Section 3.3.5.

Furthermore, Lund (1983) studied a diesel engine OER that stated the following reasons why it could effectively compete with smaller, local remanufacturers:

- The company had higher worker productivity because of its factory methods;
- it used facilities, specialized equipment, and energy more efficiently;
- the quantities it produced were large enough to justify machines requiring less skilled workers, and
- it salvaged more materials, thereby greatly reducing its requirement for new materials and the cost of new parts.

A disadvantage that larger remanufacturers have in comparison with smaller businesses is a higher cost of overhead (e.g. Munde, 2004). Although there are many advantages of OEM remanufacturing as described above from both researchers and industry, few OEMs actually carry out product remanufacturing.

The energy required to remanufacture a product is significantly less than recycling, provided the product fits the necessary production characteristics for remanufacturing (Lund, 1996). As Lund (1996) further states, it is imperative that the following characteristics are applied to the remanufacturing process to maintain profitability levels of the company:

- The product has a core, that is not consumed, discarded or does not function properly
- The product can be restored to its original state using current technologies
- The product can be mass-produced in a factory setting
- The value of a remanufactured product is close to the original product market value
- The cost associated with acquiring discarded or failed products is relatively low compared to the market value of the remanufactured product
- There are no rapid changes in the product technology, as it is difficult to mass-produce remanufacturable products that change constantly.

Of course, there are products that are remanufactured in less than optimal factory settings in terms of volume, tools, market etc. This could, for example, be the case when cellular phones are sold in Africa or Brazil or when household appliances are sold in to the Eastern parts of Europe. Although product technology changes rapidly for cellular phones, it has been found profitable to remanufacture them in South Africa (Steinhilper, 2003). Hence, the characteristics stated above by Lund should only be seen as preferable and not an absolute necessity.

For owners of older vehicles in need of repair, a remanufactured product or spare part can represent a lower-cost, lower-risk alternative to new parts. Compared to buying a new product, it also represents a potential 'win-win-win' for customers who pay less, manufacturers who earn more and the environment, since fewer new resources are consumed. (Seitz and Peattie, 2004). According to Seitz and Peattie (2004), an experienced vehicle remanufacturer in the United Kingdom found the following enablers for its business:

- Securing the supply of spare and replacement parts. Vehicle manufacturers provide spare parts for at least 15 years. After only a few years, remanufacturing becomes the only way to meet this customer commitment and supply replacement engines for previous models.
- Providing cost-effective replacements for under-warranty engines. Failed engines under two years old are replaced with a remanufactured engine. This is often not apparent to customers, and this practise produces considerable savings for the company. The exact savings vary, depending on the engine model and its age, but there are in the region of 40 percent.
- Speeding up the supply of replacement engines for customers. Although remanufacturing may take many weeks, it is faster than building a new version of a phased-out engine. This reflects the time it takes to acquire parts from suppliers and to hand-make the low-volume parts that the suppliers have stopped producing.

According to van Nunen and Zuidwijk (2004), there are several other benefits/drivers for remanufacturing. Dell offers refurbished machines and in return receives valuable information on product use by customers. Another example is Sun Microsystems, which offers return and upgrade procedures in order to secure customer investments (van Nunen and Zuidwijk, 2004).

Furthermore, Geyer and Jackson (2004) conducted an assessment in the steel industry which suggested that for the construction sector, reuse would be a 'win-win' strategy since reuse has better economic and environmental performance than recycling. Geyer and Jackson (2004) state further:

> '*… for firms that are actively exploring the potentials of supply loops, the collection of reliable data and good quality market intelligence is paramount. Companies that manage to gather this information now – rather than wait until economic and environmental pressures force them to react – will be ahead of the game'*.

A dramatic reduction in environmental impact can be made by product remanufacturing in which, in contrast to material recycling, the geometrical form of the product is retained and its associated economical and environmental value preserved (Bras and Hammond, 1996). In comparison to material recycling, there are more economic benefits to remanufacturing as well (see e.g. Cruz and Mulholland, 2000 and the results in Paper V). The remanufacturing companies in, for example, Cruz and Mulholland's study (2000) did not require government financial assistance to remain established in comparison to the Blue Box program, which recycles cans and bottles in the Greater Toronto Area (GTA), Canada.

Most of these advantages and benefits have been suitable for OEM remanufacturers, since they have good control over their products. Of course, there are advantages for independent and contracted remanufacturers, such as low overhead costs, but the biggest potential advantages are made for OEM remanufacturers.

3.2.4 Obstacles and Constraints of Remanufacturing

Differences between the management challenges for remanufacturing and those of conventional manufacturing are significant. The conventional manufacturer only has to deal with one generation of product variants at a time, and mass production volumes allow production lines to be dedicated to single products. The remanufacturer, in contrast, has to deal with small batches of products encompassing a range of product variants and generations, which complicates tool-changing, disassembly, and assembly processes. In the case of the remanufacturer, establishing the types of lean and mass production systems that manufacturers depend upon becomes practically impossible (Seitz and Peattie, 2004).

Sometimes, new spare parts must be ordered to the remanufacturing facility, which can involve long lead times. This issue is sometimes a crucial one for the remanufacturing business, as described in the 24 Hour Toner Services case in Appendix A. The scale of these delivery times – combined with product variant proliferation and the inability to predict what types of products will be returned – forces remanufacturers to maintain high inventory levels to avoid bottlenecks in parts supply (Seitz and Peattie, 2004). Recovery processes such as remanufacturing are difficult to manage due to a number of uncertainties, such as uncertainty in both processing times and required operations in the recovery process itself as well as uncertainty in quantity, quality, and timing of materials and components that are released from the recovery process. In addition, the return flows that supply the recovery processes are also uncertain in quantity, quality, and timing (van Nunen and Zuidwijk, 2004).

Geyer and Jackson (2004) have conducted research concerning the constraints in the supply loops for the recycling and reuse of products. A supply loop should be defined as constrained when any of its processes have difficulties with the output of the upstream process. The two process groups in the supply loop framework are collection and reprocessing. Figure 7 shows that this results in three material flows, each of which can be subject to a different type of constraint:

- Limited access to end-of-life products leaving the use phase,
- Limited feasibility of end-of-life product reprocessing, and
- Limited market demand for the secondary output from reprocessing.

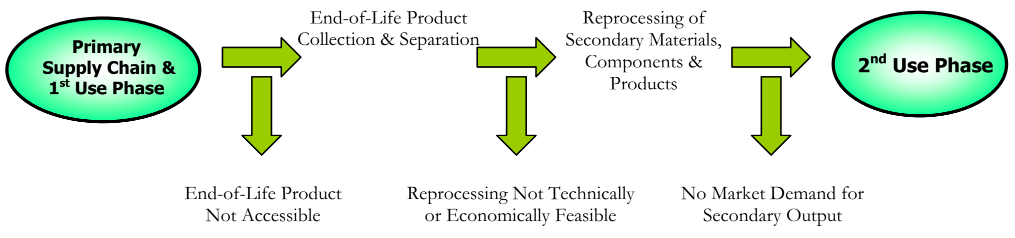


Figure 7. Three types of constraints in supply loops (based on Geyer and Jackson, 2004).

Under which conditions a supply loop is win-win is often dependant on the existence of constraints and their level of impact (Geyer and Jackson, 2004).

According to Geyer and Jackson (2004), there are two ways to overcome supply loop constraints: either to change the design of products and processes in the primary supply chain or to adapt the processes in the supply loop. From a systems perspective, the first strategy is clearly preferable and therefore often practiced when both the primary supply chain and the secondary supply loop are owned and controlled by one firm (Geyer and Jackson, 2004), a statement which is in line with the results of the remanufacturing research conducted by Jacobsson (2000).

In a survey of the American automotive industry, Hammond et al. (1998) identified costs and availability of replacement part (including cores) to be of key concern for remanufacturers. Manufacturers tend to use Design for Assembly and Manufacturing (DfA and DfM) processes, which make it difficult for parts to be reused or remanufactured. These issues, as well as several others found in the same survey for American automotive remanufacturers, were grouped into the following categories:

- The availability and cost of replacement parts
- The increased product diversity
- Cleaning
- Corrosion
- Design related issues
  - complexity
  - fastening methods
  - means of assembly and disassembly
  - increased part fragility
- Employee skills

In an interview series conducted by Guide Jr. (2000), remanufacturing executives were asked to identify the greatest threats to industry growth over the next 10 years. The majority (60 percent) cited the increased pressure to reduce remanufacturing lead times continuously, and many (38 percent) others cited the lack of formal systems (e.g. operations, accounting, logistics) for managing their business. Other threats identified included lack of cores (50 percent), products designed for disposal (34 percent), and rapid technological changes (28 percent).

3.2.5 Product Ownership

An interesting issue to deal with in remanufacturing is product ownership, which is also coupled to the type of remanufacturer that is performing the work. For independent remanufacturers, the core, i.e. discarded products must be collected or bought to their business. This means that the remanufacturer owns the cores that are to be sold as remanufactured products at the end of its process. In this case, the remanufacturer maintains the work in progress at the core inventories, inventories between steps and inventories of remanufactured products.

According to Lund (1983), the used products are not necessarily owned by the company, as it would be in a manufacturing operation. The results of an American remanufacturing survey conducted by Lund (1983) showed that remanufacturers sometimes have ownership arrangements. In the investigation, 127 remanufacturers were asked if the used product is owned by 'themselves', 'the user of the product', 'the OEM' or by some 'other' entity. The answers were analysed by market segment (automotive, industrial and commercial). In Table 4, the responses represent the mean percentage of products in each class of ownership:

Table 4: Product ownership by market segment (Lund, 1983).

Market segment	Remanu-facturer (%)	Product User (%)	OEM (%)	Other (%)	#
Automotive - including automobiles, trucks, buses, motorcycles and parts.	94	4	2	0	54
Industrial - all forms of machinery or equipment used in manufacturing or construction.	64	25	6	5	45
Commercial - equipment used in trade or services business.	51	39	6	4	28
Total					127

As can be seen in Table 4, product ownership is strongly related to market segment, i.e. which type of product is being remanufactured. If the remanufacturer has a contract with an OEM or is a part of the OEM, the ownership normally stays with the OEM. This means that the money built up in the remanufacturing inventories are connected to the OEM. In the case of a contracted remanufacturer, this means that the money built up in storage and WIP is connected to the product owner, i.e. the OEM. Furthermore, the laws of extended producer responsibilities apply to the manufacturer, and not the remanufacturer; therefore, it is the manufacturer who has the responsibility for the end-of-life treatment of products.

Manufacturing companies around the world are striving to increase their revenues and profitability through, for example, obtaining a larger share of the market and controlling a larger share of the product value chain. This can potentially be achieved, in concert with environmental benefits, by a change or at least a move towards a higher degree of functional sales (Lindahl and Ölundh, 2001). The business concept of functional sales can be defined as follows:

> '…*to offer from a life-cycle-perspective a functional solution that fulfils a defined customer need. The focus is, with reference to the customer value (defined customer need), to optimize the functional solution from a life-cycle perspective. The functional solution can consist of combinations of systems, physical products and services' (Lindahl and Ölundh 2001).*

Functional sales can be achieved, for instance, by selling the number of photocopies made, instead of selling the physical photocopy machine. The functional sale business strategy is related to other strategies, such as businesses dealing with renting and leasing. Functional sales and related theories are described in detail by Mont (2004) who addresses this business strategy as a product service system (PSS). Paper IV further discusses the business potential of linking functional sales with product remanufacturing.

A foundation for functional sales is that product ownership stays with the service provider, who is often the manufacturer as well. By remanufacturing the physical products for functional sales, the service provider/manufacturer has the possibility to provide the same product to customers in several functional sales contracts. The remanufacturing of products for functional sales is a way to make the concept of functional sales more profitable and environmentally preferable.

3.2.6 Reverse Logistics

Considering the business of remanufacturing, there are many aspects that influence profitability. Product returns and their reverse supply chains represent an opportunity to create a value stream, not an automatic loss. Reverse supply chains deserve as much attention at the corporate level as forward supply chains, and should therefore be managed as business processes that can create value for the company (Blackburn et al., 2004).

In research studies conducted by Blackburn et al. (2004), it was shown that the time value of returned products varied widely across industries and product categories. Time-sensitive, consumer electronics products such as PCs can lose value at rates in excess of 1 percent per week, and the rate increases as these products near the end of their life cycles. At these rates, returned products can lose up to 10-20 percent of their value simply due to time delays in the evaluation and disposition process (Blackburn et al., 2004). The differences in marginal value of time (MVT) for returns are illustrated in Figure 8.

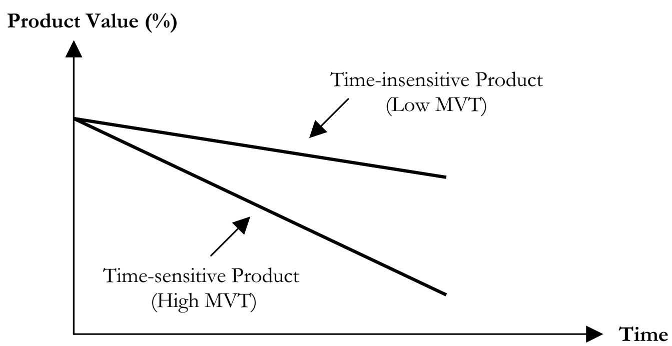


Figure 8. Differences in marginal value of time for returns (adapted from Blackburn et al., 2004).

The type of product affects the possibilities of making the reverse supply chains as profitable as possible. For example, diesel engines would be less sensitive to remanufacture in comparison with personal computers. According to Fisher (1997) there are two different reverse supply chain strategies to choose from: efficient and responsive.

- Efficient – a supply chain designed to deliver products at low cost.
- Responsive – a supply chain designed for speed of response.

Within this framework, there is an appropriate matching of product to supply chain efficient supply chains are best for ‘functional products’, while responsive chains are best for ‘innovative products’. To translate the product classifications of ‘functional’ and 'innovative', these terms roughly correspond to products with low and high marginal values of time, respectively (Blackburn et al., 2004). Innovative, short life-cycle products such as laptop computers have a high marginal value of time, whereas products such as power tools of disposable cameras are less time-sensitive and have low marginal values of time. Adopting Fisher's strategies for the product types generates the following matrix (Figure 9):

	Efficient Chain	Responsive Chain
Low MVT Product	**Match**	**No Match**
High MVT Product	**No Match**	**Match**

Figure 9. Time-based reverse supply chain design strategy (Blackburn et al., 2004)

Furthermore, the major structural difference between efficient and response reverse supply chains is the positioning of the evaluation activity in the supply chain – that is, where in the chain that testing and evaluation are conducted in order to determine the condition of the product. If cost efficiency is the objective, then the returns supply chain should be designed to centralize the evaluation activity. On the other hand, if responsiveness is the goal, then a decentralized evaluation activity is needed to minimize time delays in processing returns (Blackburn et al., 2004). These two types are illustrated in the following Figures (10 and 11):

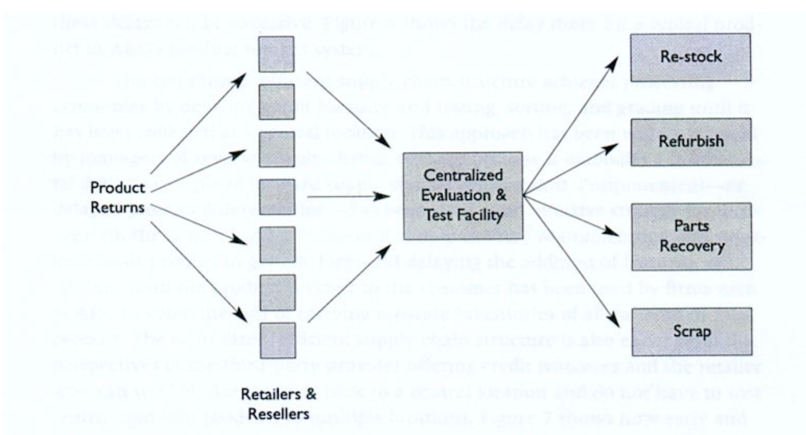


Figure 10. Centralised, efficient reverse supply chain (Blackburn et al., 2004).

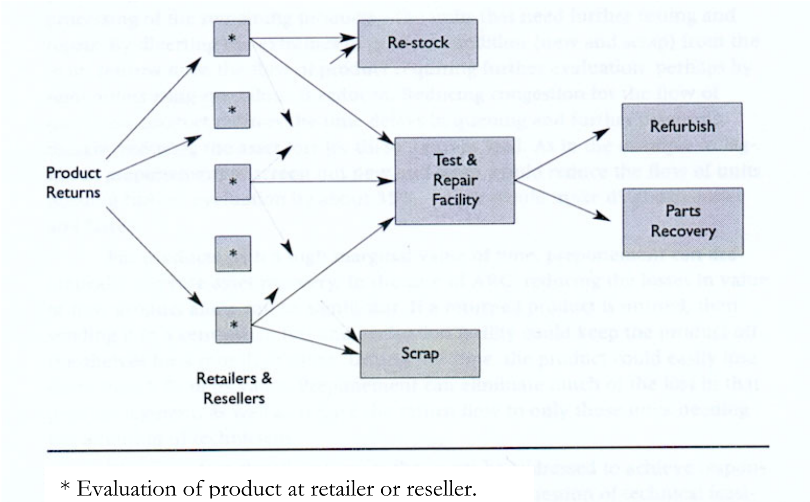


Figure 11. Decentralised, responsive, reverse supply chain (adapted from Blackburn et al., 2004).

According to Blackburn et al., (2004) there are two significant issues that must be addressed to achieve responsive, decentralised reverse supply chains. First is the question of technical feasibility – that is, being able to determine the condition of the product return in the field quickly and inexpensively. Second is the question of how to induce the reseller to do these activities at the point of return; incentive alignment via shared savings contracts may be the best way to induce cooperation between the manufacturer and the reseller (Blackburn et al., 2004).

To summarise this research by Blackburn at al (2004), it is important to recognize that the significant value remaining in product returns and their time sensitivity are keys to designing their reverse supply chains. This is especially true for maturing markets such as consumer electronics, where there are declining margins, where poorly handled return streams and increasing returns volumes can quickly erode profits significantly.

3.2.7 Examples from the Remanufacturing Industry

Although there are many potential benefits for OEMs to remanufacture their own products as Section 3.2.3. implied, many smaller independent remanufacturers conduct their businesses with good profit margins. In fact, according to a survey conducted in the USA by Lund (1996), the majority of remanufacturers are independent. With support from the Argonne National Laboratory, a team of researchers at Boston University under the direction of Professor Robert T Lund established a database of 9 903 American remanufacturers. Furthermore, on the basis of the information from this database plus further assessments from industry experts, they arrived at estimates for the total American remanufacturing industry. Table 5 shows the distribution of firms per industry sector:

Table 5: Distribution of remanufacturing firms sampled by industry sector (Lund, 1996).

Industry Sector	Products	Firms in the Database	Estimated firms not in Database	Total
Automotive	Alternators, Starter Motors, Water Pumps, Clutches and Engines	4 536	46 000	50 536
Compressors & Refrigeration	Air conditioner and Refrigerator Compress.	55	100	155
Electrical Apparatus	Transformers, Electrical Mot--ors and Switch gear	2 231	11 000	13 231
Machinery	Machinery and Equipment for various industries	90	30	120
Office Furniture	Desks, Files and Partitions	220	500	720
Tires, retreaded	Truck, Auto and Off-road Tires	1 210	180	1 390
Toner Cartridges	Laser toner cartridges Ink jet cartridges	1 401	5 100	6 501
Valves, industrial	Control & Relief valves	110	300	410
Other	Diverse	50	200	250
Totals		9 903	63 410	73 313

This table shows that there is a majority of remanufacturers in the automotive sector. The automotive industry has for many years remanufactured cars by reusing engines and other parts that can be used in other cars before scrapping. Looking at this table, one should remember that the survey is nearly ten years old. Today, there could be many other products having a larger share of the remanufacturing industry - single-use cameras and toner cartridges are two such examples, Furthermore, the survey shows how many companies that are involved in the sector, but not the actual remanufacturing volumes. In other words, the survey provides a picture of which remanufacturing industries were most dominant ten years ago.

A survey of the Swedish remanufacturing industry was conducted during summer 2004. A M.Sc. student performed this survey in a 20-week project, which was developed and is supervised by the author. Although Sweden has a small population and market, remanufacturing companies in various sectors have been found, e.g. the automotive, electrical apparatus, toner cartridges, furniture, personal computers and medical equipment industries. This survey has also shown that most remanufacturers are independent and are convinced that their business as remanufacturers will increase in the near future. (Mårtén, 2004)

Some other areas of remanufacturing that have been highlighted the last few years are photocopy machines and single-use cameras; Xerox, a leader in extensive remanufacturing of its own photocopiers[13], is a prime example. The company concurrently plans and designs its manufacturing and remanufacturing facilities for new models, and most of its products are remanufactured (Ishii, 1998). This operation is successful partly because the

[13] The remanufacturing facility is now under the operation of Flextronics.

company has so many photocopiers in the market on leasing agreements. Other companies like Kodak and FUJI Film utilize the fact that single-use cameras must be returned in order to develop the film inside. By using this product idea, almost all cameras are taken care of and reused, either as recycled material or reused parts. Electrolux AB remanufactures household appliances in Sweden and garden equipment in the United States; furthermore, Electrolux remanufactures commercial cleaning equipment (see the case study by Jacobsson, 2000). All of the four companies mentioned above (Xerox, Kodak, FUJI Film and Electrolux) are OEM remanufacturers.

As previously stated in Section 3.2.1, *reconditioning* and *refurbishing* are other terms that are used by some companies. The variation of terms of nearly the same concept makes surveys in the area harder to perform.

3.3 Product Development

3.3.1 The Product Development Process

Traditionally, the Product Development Process (PDP) includes numerous steps. Different authors describe these steps, or phases, in a product's development somewhat differently. Even companies have their own view of how to proceed in the process, although they all have great similarities. In this section, the product development process will be described in brief, mainly based on Ulrich and Eppinger (2003). Other researchers have their view of the product development process (see e.g. Ullman, 1997, Ertas and Jones, 1996, Roozenburg and Eekels, 1996, Cross, 2001, and Pahl and Beitz, 2001), but they are quite similar to the one described by Ulrich and Eppinger, whose PDP was considered by the author of this dissertation to be both pedagogical and easy to understand. Ulrich and Eppinger suggest that the generic product development process should be divided into following six phases (Figure 12):

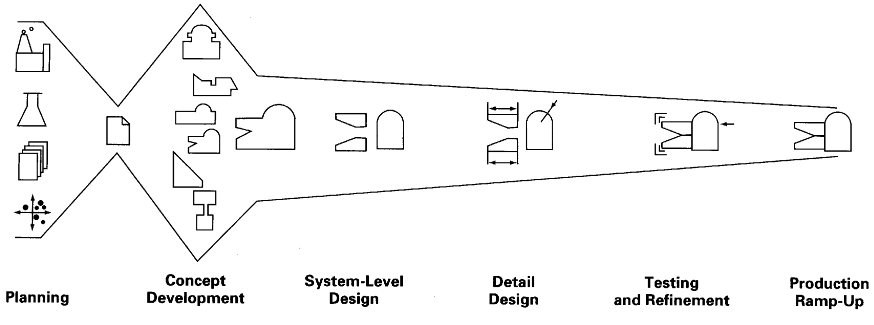


Figure 12. The generic product development process (Ulrich and Eppinger, 2000).

To manage a product development project, the design company needs to set up a project team with a project leader. This team usually consists of people from different departments with different skills. For example, it is important to have people in the group from production, in order to adapt the product for production. According to Ulrich and Eppinger (2000), the design team members for product development can be organised in two different ways: according to their function or according to the projects they work on. A function is in organisational terms an area of responsibility, usually involving specialised education, training or experience. The classic functions in product development organisations are marketing, design and manufacturing. A project, on the other hand, is the set of activities in the product development process described above for a particular product. These two types of organisation can and preferably do overlap. In functional organisations, the organisational links are primarily among those who perform similar functions, in contrast with project organisations where the organisational links are primarily among those who work in the same project, as shown in Figure 13. It is preferably to have a mix of the two types of organisation, which in industry is also called integrated product team (IPT), design-build team (DBT) or product development team (PDT). The terms all emphasise the cross-functional nature of these teams (Ulrich and Eppinger, 2000).

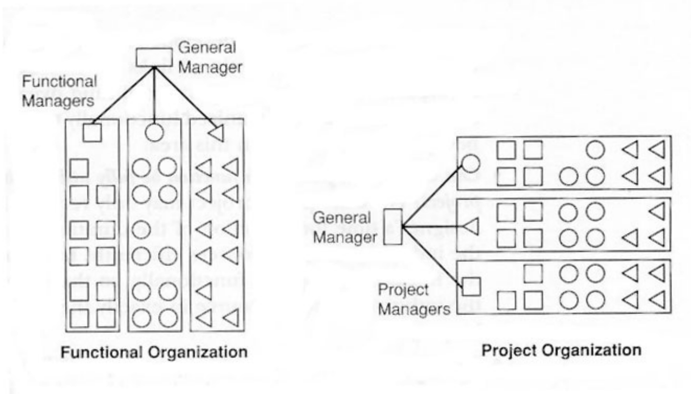


Figure 13. Different types of design teams, adapted from Ulrich and Eppinger (2003).

According to Amezquita and Bras (1996), the most effective way to boost remanufacturing is with an integrated product and process design approach. This way of managing a product's development is called Concurrent Engineering (CE) or, alternatively, Integrated Product and Process Development (IPPD). With CE, people with different skills work together; CE, is also, according to Huang (1996), an ideal environment for product development. Its objectives include improving quality, reducing costs, compressing cycle times, increasing flexibility, raising productivity and efficiency, and improving social image. These goals can be fulfilled through co-operative teamwork between multiple disciplinary functions to consider all interacting issues in designing products, processes and systems from conception through production to retirement. A design tool that offers an effective approach to implement CE is Design for X (DfX), further explained in the following section.

3.3.2 Design for X (DfX)

Design for X (DfX) is both a philosophy and a methodology that can help companies to change the way that they manage product development and become more competitive. A designer has a specific design aspect in mind, such as assembly. This means that the product is enhanced concerning that aspect, or property 'X'. Different DfX methodologies exist where 'X' can stand for Environment, Recycling, Assembly, Disassembly, Manufacturing, Remanufacturing etc. Examples of DfX methods are guidelines, checklists and software focusing on the 'X' aspect. According to Huang (1996), a DfX method supports the following functions for a designing company:

- Gather and present facts about products and processes.
- Clarify and analyse relationships between products and processes.
- Measure performance.
- Highlight strengths and weaknesses and compare alternatives.
- Diagnose why an area is strong or weak.
- Provide redesign advice on how a design can be improved.
- Predict what-if effects.
- Carry out improvements.
- Allow iteration to take place.

In this dissertation, the design focus is on Design for Environment (DfE) and, in particular, Design for Remanufacturing (DfRem), which will be further described later in this chapter.

Sometimes, conflicts arise between different DfX methodologies, as Shu and Flowers (1999) describe in an article showing conflict between Design for Remanufacturing and Design for Assembly and Recycling. For example, two product parts can be joined with a snap-fit of the same material as the parts being joined together. By doing this, the parts are quickly assembled and do not need to be disassembled when the parts are material recycled. If the parts are going to be remanufactured, however, the parts might need to be disassembled, and this can sometimes be tricky if the snap-fit is fragile or hard to access. The conflict of manufacturers focusing on DfA and DfM was also brought up in the remanufacturer survey conducted by Hammond et al (1998), see Section 3.2.4.

3.3.3 Integration of Environmental aspects in PDP

A way of achieving environmentally adapted products is through a design for X strategy (see Section 3.5.3), where the 'X' is an 'E', standing for Environment. Design for Environment (DfE) is also known in the literature as *Ecodesign*, *Environmentally Conscious Design* or *Life Cycle Design*. These terms stand for almost the same thing, e.g., Life Cycle Design has similar goals to DfE, although it has another origin (Garner and Keoleian, 1995).

As the DfE chapter will describe later, it is preferable to have environmental considerations during the entire product development process (see Section 3.3.4.). There are many DfE tools that have been developed by academia and industry (see e.g. Simon et al., 1998). According to McAloone (2000), however, not much effort has been made on integrating these tools into the design process, and the question of whether there should be procedures for companies to follow when first beginning to implement this environmental thinking has not been sufficiently considered. On the other hand, some research has dealt with this integration question.

For example, Ritzén (2000) studied the challenge of integrating the environmental issues into the product development process, and suggested a cyclical implementation process. Figure 14 illustrates what requirements are needed for implementing environmental issues in the product development process.

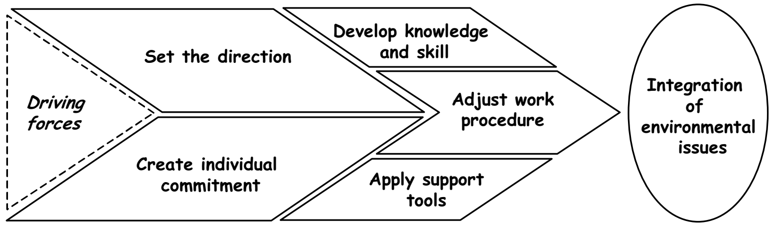


Figure 14. Proactive measures recommended for integration of environmental aspects, which push changes towards the environmental adaptation of products (Ritzén, 2000).

Furthermore, Furuhjelm (2000) developed a model showing how to integrate the end-of-life aspects into product development, including an analysis of the areas of market demand, legislation and end-of-life system, as illustrated in Figure 15.

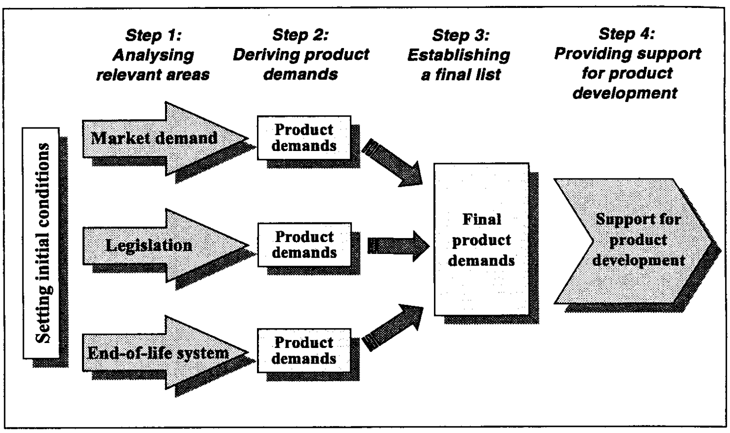


Figure 15. An approach to how end-of-life aspects could be incorporated in a systematic way into product development (Furuhjelm, 2000).

According to Amezquita and Bras (1996), the most effective way to boost remanufacturing is through an integrated product and process design approach. Moreover, remanufacturing is an action preventing environmental impacts from occurring, and it is preferable that design for remanufacturing has been considered during product development (Bergendahl, 1998).

3.3.4 Design for Environment (DfE)

The idea of design for environment (DfE), also called ecodesign, was developed during the 1970s along with an explosion in environmental consciousness. At that time, much environmental research focus was placed on emissions from factories. These emission problems were at first solved through end-of-pipe-solutions, with various filtering and diluting techniques. Despite this 30-year history of environmental research, DfE has worked its way into the product development process until the 1990s (US Congress, 1992). This shows that the focus of environmental research has changed more and more towards preventive strategies, in order to decrease environmental impact. Some examples of preventive strategies are:

- Reduce product material
- Use materials that do not harm the environment
- Use materials that are recyclable or reusable
- Use materials that are recycled
- Structure the product part for easy repair, reuse, recycling
- Use joining methods facilitating part changes

DfE has been known in research and industry for a number of years, mentioned earlier. Much research has been conducted in this area, with the overall purpose of environmental conscious design being to reduce the total environmental load during a product life cycle - while society's needs still are provided (Ryding et al., 1995). However, many other definitions for Ecodesign and Design for Environment have been stated (see for example Graedel and Allenby, 1995, and Brezet and van Hemel, 1997). The definition used in this dissertation is the following:

> *"An approach to design where all the environmental impacts of a product are considered over the product's life" (Dewberry and Goggin, 1996).*

When designing products for the environment, a life cycle perspective is needed, as the definitions above suggest. This means that the designer needs to consider all product life phases: *extraction of raw material*, *production of material and components*, *manufacturing*, and *usage* and *disposal/end-of-life treatment* (see e.g. Furuhjelm, 2000).

An important issue of DfE is to investigate what the market demands are for eco-designed products. For example, if there is no demand for remanufactured products, it is almost impossible for the remanufacturing companies to sell the products back on the market, at least at a profit. A market investigation showed that less then four percent of the population is willing to pay a significant premium for environmentally-adapted products, although more than 70 percent of the market would choose a product/service with similar quality and price if it was environmentally adapted (Cohen-Rosenthal, 1998). Another study, based on 148 consumer interviews, says that consumers are willing to pay a higher price for environmentally preferable products but are not ready to go out of their way to look for such products (Bhate and Lawler, 1997). Both these studies show that there is a market for environmentally adapted products if they are marketed and sold in the right manner. This also shows the importance for manufacturers to expose and market their environmentally adapted products to customers.

Companies have various ways of implementing DfE in the product development process, and there have been tools developed for choosing the right strategy (see, for example, Simon et al., 1999). In the past several years, research has revealed that designers must clearly define their end-of-life strategy before considering recyclability or remanufacturability (Ishii, 1998).

In a model developed by Brezet and Van Hemel called *the ecodesign strategy wheel, eight* different strategies are presented, as shown in Figure 16. The chosen strategy, or combined strategies, is often product type-dependent, e.g., various products create the heaviest environmental burden in different phases of their lives.

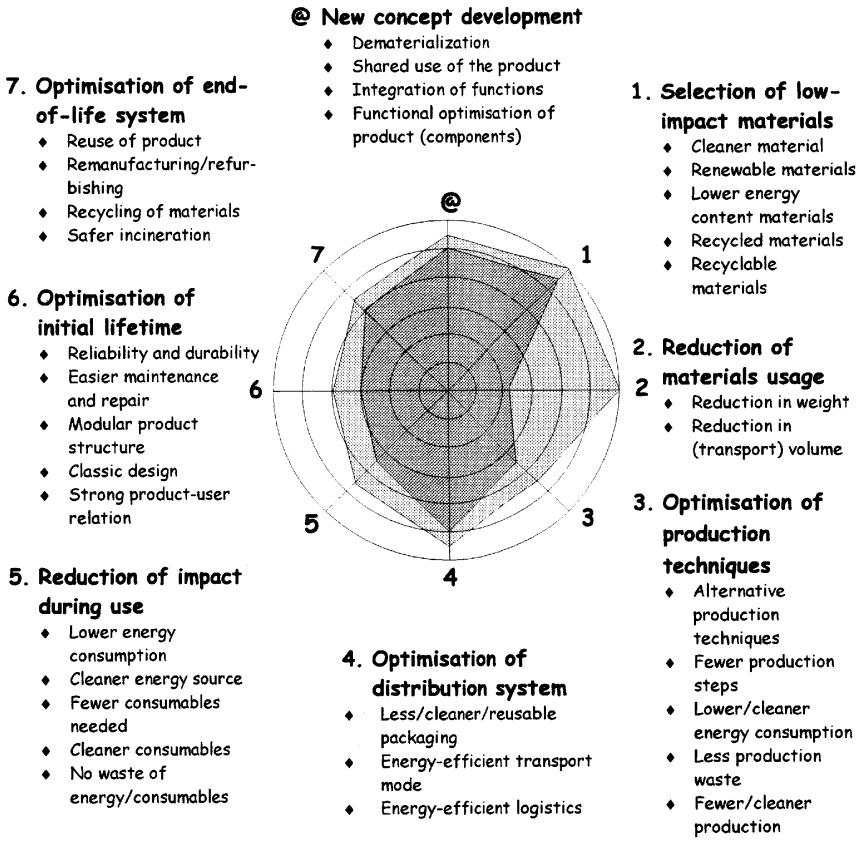


Figure 16. Eight different strategies to choose from or combine when designing for the environment (Brezet and Van Hemel, 1997).

The Ecodesign strategy wheel (Figure 16) illustrates different options that manufacturers can choose and combine strategies from. The impact of these strategies is very product type-dependant. In Figure 16, one can see that spike 7 in the wheel, 'Optimisation of End-of-life system', includes design for remanufacturing. This is the most interesting strategy concerning this dissertation. The whereabouts of Design for Remanufacturing (DfRem) is further described the following section.

3.3.5 Design for Remanufacturing

Design for remanufacturing could be seen as a part of design for environment. Within design for remanufacturing, many aspects must be considered, such as ease of disassembly, sorting, cleaning, refurbishment, reassembly and testing. Product design that facilitates any of the steps involved in remanufacture will also facilitate remanufacture

(Shu and Flowers, 1999). Facilitating product and part reuse is an essential goal in design for remanufacture. Naturally, it is possible to remanufacture products that are not designed for this purpose; still, it is preferable to have them designed for remanufacture. Upgrading the functions of the products in accordance with customer requirements can prolong their functional life. Such a product life design strategy is crucial for optimisation of product usage in terms of a closed loop product life cycle. Modular design of products is a key technical issue for realising this concept (Kimura, 1997).

Design for remanufacturing is a relatively new DfX-technology, which along with design for recycling (DfR) is a key element of the overall concept of product design for the sustainability of our environment (Steinhilper, 1998). With design for remanufacturing, money can be earned as a result of decreasing waste management costs, descreasing disassembly times and increasing remanufacturing yield for products re-entering the life-cycle use phase. Research has shown that design for remanufacturing is profitable for copy machines (Kerr, 1999). With old assemblies or equipment not designed for remanufacture, it is seldom possible to do more than recover the materials, and even that may be difficult and costly (Graedel and Allenby, 1996).

Structuring the product with remanufacturing in mind is important for DfRem. This means, for example, allowing easy access to parts that need to be changed often. Further, the choices of fastening and joining methods are crucial for disassembly (Lundgren and Franzén, 1995). Shu and Flowers (1999) have focused on these methods and developed a software program for choosing the right fastening and joining methods, as earlier described.

Moreover, a product's remanufacturability can be measured. Bras and Hammond (1996) have developed design for remanufacturing metrics, applied to several product case studies, which indicate how well a product is design for remanufacturing. Furthermore, Shu and Flowers have created a product part reliability model, from which one can estimate different recycling and remanufacturing costs for different product concepts (Shu and Flowers, 1998).

It may be argued that adapting a product for disassembly, cleaning or reassembly is meaningless if the product or its parts are not intended to be reused (Shu and Flowers, 1995). This might not always be true, however, since it could be very useful to adapt/design products for remanufacturing considering future take-back laws. These take-back laws would put pressure on the producers to take back a certain percentage of manufactured products.

3.3.6 Product properties

Products are commonly described by their properties. A product property is, according to Hubka and Eder (1988) defined as *"any characteristic of a product that belongs to it and characterises it"*. Properties are of various kinds, and may therefore be specified into different classes. Hubka and Eder (1988) divide them into internal and external properties as shown in Figure 17:

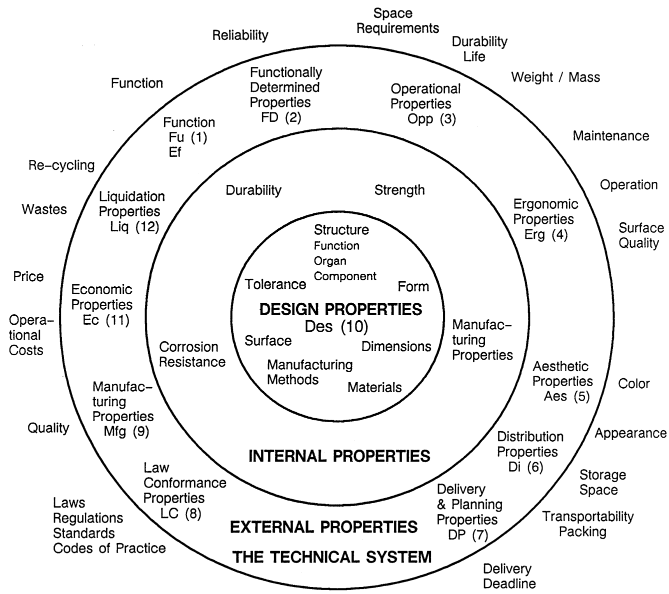


Figure 17. Relationships between classes of properties (Hubka and Eder, 1988).

An important issue when studying product properties is to understand how the properties are related to each other. Internal product properties are achieved through the design properties set by the product designer. Setting the design properties, the designer has the ability to determine the product part's form, dimensions, materials, surface quality, tolerance and their relation to each other as in, for example, the internal layout of the product. External product properties support these internal considerations and are determined through the demands from the surroundings of the product, as shown in Figure 15 above (Hubka and Eder, 1988).

According to Tjalve (1978), desired product properties are derived from co-operation between the designer and the customer. It is the task for the designer to make the final product properties as close as possible to the properties that the customer desires. The basic variables that determine the final product properties are those which are to be determined by the designer.

3.4 Industrial Ecology

3.4.1 Manufacturing companies and the Environment

Manufacturing companies have and will always have the ambition to satisfy their customer's needs by providing a physical product and/or a service performed by the physical product. This process affects society and the company's surroundings. The evaluation of these industrial-environmental interactions is often called Industrial Ecology. With industrial ecology, an attempt is made to create a framework for understanding the impacts of industrial systems on the environment. This new framework serves to identify and then implement strategies to reduce the environmental impacts of products and processes associated with industrial systems, with the ultimate goal of sustainable development (Garner and Keoleian, 1995). Graedel and Allenby (1995) define Industrial Ecology as follows[14]:

> *'Industrial Ecology is 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 optimised include resources, energy, and capital'.*

To achieve industrial ecology, the interactive parts, e.g., companies, authorities and societal groups, need to have a well-functioning co-operation striving towards the same goal. A precondition for having this good co-operation is each of the parts understands well how their systems interact with the environment.

A goal of industrial ecology is to stimulate the evolution of the industrial system so that it shares the same characteristics as natural systems. Industrial ecology would ideally reach the dynamic equilibrium and high degree of interconnectedness and integration that exist in nature (Garner and Keoleian, 1995). Another goal of industrial ecology is to change the linear nature of our industrial system, where raw materials are used and products, by-products, and wastes are produced, to a cyclical system where the wastes are reused as energy or raw materials for another product or process. The goals of industrial ecology are reached through co-operation. These co-operative efforts have different actors depending on what perspective is used. Co-operation can be successfully achieved in several areas. In the following list, some areas where companies can co-operate in an industrial ecology manner are presented (Cohen-Rosenthal, 1998):

- Material
- Energy
- Logistics
- Marketing
- Production/service processes
- Environment/health/safety
- Human resources
- Information and communication systems
- Community connections

One way to locally develop an industrial ecosystem is by developing eco-industrial parks, which are communities of manufacturing and service businesses seeking environmental and economical performance through collaboration in managing environmental and resource issues, including energy, water, and materials. By doing so, companies obtain greater benefits than if they attempted to optimise performance on their own. The goal is

[14] Nine other definitions can be found in an appendix to an article written by Garner and Keoleian (1995).

to improve the economical performance of the participating companies while minimising their environmental impact (Lowe et al., 1996)

3.4.2 Product Recovery

As mentioned in the previous chapter, one goal of Industrial Ecology is to recover products, as dealt with in this chapter. Product recovery, however, is not a new phenomenon. There are many ways of closing the material loop through product recovery. When a product has reached its end-of-life phase, there are several options to choose from; for example, the product could be placed in a landfill, stored, incinerated, repaired, reused, or recycled, or a combination of these. Figure 18 below illustrates the material flow for products throughout their lives and the alternatives at the end-of-life phase:

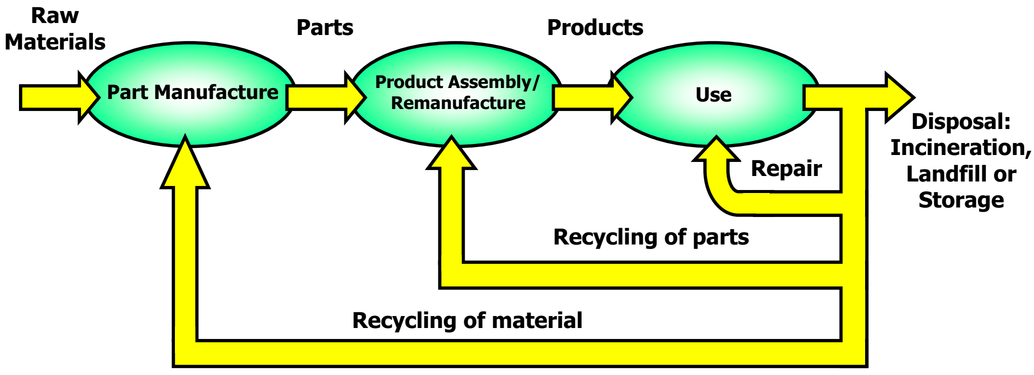


Figure 18. The life of products (Sundin, 2002).

At first, product parts are processed and manufactured from raw and recycled materials. The manufactured parts are then assembled into new or remanufactured products, together with recycled parts. At present, it is most common to assemble new parts into new products without using recycled parts or materials. During the use phase, the products could be repaired and maintained. These actions extend the product's life, and can be seen as a reuse of entire products. Finally, one of the end-of-life options is selected, as previously mentioned and shown in Figure 18 above.

The choice of end-of-life option often depends on product type. From an environmental point of view, it is often preferable to recycle as much of the product as possible, since most material and effort then gets reused. This is of course dependent on if, for example, the process or transports are increased through product reuse in comparison to other options. Recycling decisions must be made from a logical perspective, which often requires the low-grade disposal of old products not designed for recycling. Therefore, the following priority list in Figure 19 should be seen as a guide, and not an imperative (Graedel and Allenby, 1996).

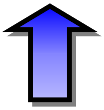
Usually most preferable:	Reduce materials content
	Reuse components/refurbish assemblies
	Remanufacture
	Recycle materials
	Incinerate for energy (if safe)
Usually least preferable:	Dispose of as waste

Figure 19. Priority list for recycling (Graedel and Allenby, 1996).

This list of priority can be seen in other environmental literature. For example, Ryding et al. (1995) divide the end-of-life options as a general rule into the following four categories, in decreasing priority:

1. Reuse
2. Material recycling
3. Energy recovery
4. Landfill

The specific product end-of-life decision should, from a material resource perspective, be the one that consumes the least amount of resources. According to Ryding et al. (1995) much products today are going to end-of-life option 3 and 4 (energy recovery and landfill) instead of the options 1 and 2 (reuse and material recycling). The number of products going to these options ought to be alternated in order to achieve more circular material flows (Ryding et al., 1995).

To overcome environmental shortcomings associated with landfill and incineration, preventive strategies are being increasingly adopted (Furuhjelm, 2000). During the last decade, many initiatives have been undertaken aiming at increasing the recovery rate of products and materials and enhancing their reutilization. In this respect, the following trends can be identified (Furuhjelm, 2000):

- An expansion of the recycling market has taken place. Regarding the supply side, the volume of products being collected for special treatment is increasing, as well as the number of different product groups. On the demand side, companies are growing and the number of firms involved is rising.

- Producers show increasing interest in the management of their end-of-life products. A number of producing companies have set up their own recycling facilities and others deal with the question through a branch organisation.

- There is technical development in the field of end-of-life treatment. New equipment is being developed, for example tools for application during dismantling, and equipment for more refined material separation.

Remanufacturing is, as mentioned before, an end-of-life option where parts or components of a product are reused. Material recycling is, on the other hand, often performed by means of a product shredder, where outgoing material fragments are sorted into different categories and thereby further separated by such means as airflow and magnets (see examples in e.g. Furuhjelm, 2000). When a pure material fraction is gained, the sorted material can be melted and reused in part manufacture as a recycled material. With material recycling, the time and economical efforts spent in part manufacturing and product assembly are lost. Recycling of parts (remanufacturing) does, on the other hand, regain these amounts of time, costs and material put into the parts from the start. When products are incinerated, energy can be regained and the rest, e.g. ash, takes only minimal space in landfills. The end-of-life options of incineration and placing products in landfills usually generates emissions to air, water and/or soil. In some countries, like Germany, there is a shortage of landfill space, which leads to longer transports of products going to landfill.

Another way for manufacturing companies to deal with their environmental issues than through product design, as described in Section 3.3.4 and 3.3.5., is by adopting an environmental management system. The two means of environmental efforts, DfE and EMS can be integrated as the fifth research question addresses. In the following section the concept of EMS is further described.

3.4.3 Environmental Management Systems (EMS)

In order to meet the environmental demands and laws that were introduced during the late 1970s and 1980s, systems for controlling environmental management were needed. An environmental management system (EMS) can be seen as a management tool that can be used by a company, or another type of organization, to steer and control its environmental efforts (Ammenberg, 2003). The EMSs are voluntary to incorporate, but in some cases pressure from various stakeholders can more or less force companies to adopt an EMS.

Environmental management systems are often regulated and/or standardised. There are two dominating EMS standards/regulations on the market today. The first is the standard ISO 14001, which is an ISO-standard for which companies all over the world can be certified. The standard is derived partly from the Rio-1992 summit, and was put in force in the mid-1990s (Ammenberg, 2004). In this case, external auditors from accredited firms perform audits to make sure the certified companies fulfil the standard. Hence, the external auditors have an important impact of the manufacturing companies that have ISO14001 standardised EMSs. In December 2003, more than 61,000 companies were ISO14001 certified (ISO World[15], 2004).

The other dominant EMS standard is the Eco-Management and Audit Scheme (EMAS), which is an European Union regulation and thus applies to European companies. The EMAS regulation was launched in 1993 and put in force 1995. In 2001, it was further revised. By fall 2004, 4,029 sites in 3,021 organisations were EMAS registered. Most of them are companies from the industrial sector, but since mid-2001, when EMAS was opened to all other economic activities, more and more companies from the service sector and local authorities have joined the scheme (EU–EMAS[16], 2004).

[15]Reference taken from: http://www.ecology.or.jp/isoworld/english/analy14k.htm at 2004-10-06
[16]Reference taken from: http://europa.eu.int/comm/environment/emas/about/participate/sites_en.htm at 2004-10-06.

As described in the introduction, incorporating EMSs standards or regulations (as ISO14001 or EMAS) could be a means to achieve a more sustainable development. However, there is doubt whether standardised EMSs reduce a certified company's environmental impacts (see e.g. Ammenberg, 2003). On the other hand, EMSs can be used to structure and strengthen a company's environmental efforts, and many companies surely have achieved important reductions in terms of environmental impacts by using an EMS (Ammenberg, 2003). Furthermore, Stenzel (2000) has found the following four motives for international companies to incorporate ISO14001:

- To promote sustainable development
- To harmonize standards and procedures worldwide
- To promote a new paradigm of self-management as an alternative to traditional regulation
- To forestall further government regulation

Many management systems are operated through the steps of the Deming cycle. This is also valid for the environmental management systems. The Deming cycle has the following four steps which when applied correctly ensure that the operation of the management is systematic and structural (Ammenberg, 2004). Figure 20 illustrates the cycle including the following general steps;

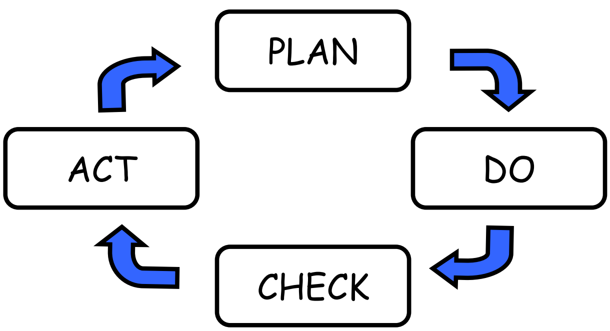


Figure 20. The Deming cycle showing the general steps for operating a management system.

In EMS terms, these steps work for both companies that are introducing and revising their EMSs. Working with the cycle, the company needs to set up a goal or a vision of what they want to achieve with their management systems. For EMSs, the cycle steps include, for example:

PLAN – the company's environmental impacts are explored and ranked in importance. Current legislation is overlooked. Goals for the company's environmental work are set together with the programs reaching them.

DO – The organisation and responsibilities are set. Necessary education and communication is performed. Reports and documents are written. An emergency plan is set.

CHECK – Processes are monitored. Measurements are performed. Measurements are compared with previously set goals. Corrections and preventive actions are made. The management system is audited.

ACT – The management are evaluating the EMS.

This is the structure of how to manage the environmental management system according to the ISO14001 standard. (Ammenberg, 2004). The ISO14001 standard is described in detail in ISO (1996).

This finishes the theoretical foundation. Of course the areas could be explored in more detail and even other research areas could have been elucidated but these that were brought up are the ones that were found related to the remanufacturing research in this dissertation. Next chapter describes the research results.

4 Research Results

This chapter contains the results from the analyses, which address the five research questions specified in Chapter 1. The research questions are brought up in each subchapter starting with addressing research question 1 and continuing until research question 5.

4.1 Environmental perspectives on Remanufacturing

The first research question stated in the introductory chapter was dealing with the environmental aspects of remanufacturing. In the methodology chapter the methodology for addressing this question was described. The results begin with what was found from studying literature about environmental aspects concerning the concept of remanufacturing. A research overview is given including results from two case studies of environmental analysis of remanufacturing of copy machines and gasoline engines, respectively (see Kerr, 1999; and Smith and Keoleian, 2004). Furthermore, the results from analysing Electrolux's household appliance remanufacturing in Sweden, are described.

4.1.1 Literature Study

Studying literature concerning the environmental impacts of remanufacturing many researchers consider the concept of remanufacturing as one of the most preferable options to choose when deciding end-of-life scenario (see e.g. Greadel and Allenby (1996), Ryding et al. (1995), Jacobsson (2000), and Steinhilper (1998). The energy required to remanufacture a product is significantly less than recycling; provided the product fits the necessary production characteristics of remanufacturing (Lund, 1996). Some of these considerations are brought up in the theoretical foundation, see Section 3.2. Much of this research refers to the fact that with remanufacturing the efforts put into manufacturing for shaping the product and its parts is salvaged in comparison to for example material recycling.

There are few thorough research studies found of environmental remanufacturing analyses. One example of an analysis conducted by Kerr (1999) is the case of remanufacturing of Xerox copy machines. Kerr performed a comparison between the remanufacturing of an ordinary designed copy machine and a copy machine that was designed to facilitate remanufacture. For the Xerox model DC 265, which has been designed for remanufacturing (as opposite to the Xerox model 5100), the savings of energy equal a factor of 3.1 and those of materials and landfill waste a factor of 1.9.

Another study analysing environmental and economic perspectives on the remanufacturing of gasoline engines was conducted by Smith and Keoleian (2004). They developed a life-cycle assessment (LCA) model in order to investigate energy savings and pollution prevention that were achieved in the United States through remanufacturing of a mid-sized automotive gasoline engine. Furthermore, a comparison was made to an original equipment manufacturer manufacturing a new engine. A typical full-service machine shop, which is representative of 55 percent of the engine remanufacturers in the United States, was inventoried, and three scenarios for part replacement were analysed. The life-cycle model showed that the remanufactured engine could be produced with 68 percent to 83 percent less energy and 73 percent to 87 percent fewer carbon dioxide (CO_2) emissions. Furthermore, the model showed significant savings for other air emissions as well, with 48 percent to 88 percent carbon monoxide (CO) reductions, 72 percent to 85 percent nitrogen oxide (NO_X) reductions, 71 percent to 84 percent sulphur oxide (SO_X) reduction, and 50 percent to 61 percent non-methane hydrocarbon reductions. Raw material consumption was reduced by 26 percent to 90 percent, solid waste generation was reduced by 65 percent to 88 percent. The comparison of environmental burdens was accompanied by an economic survey of suppliers of new and remanufactured automotive engines showing a price difference for the consumer between 30 percent to 53 percent for the remanufactured engine, with the greatest savings realized when the remanufactured engine is purchased directly from the remanufacturer. (Smith and Keoleian, 2004)

Although these figures show economic and environmental benefits for remanufacturing in comparison to new manufacturing, the study also showed that a small change in fuel efficiency could reduce the environmental benefits of remanufacturing. These kinds of issues are further discussed in the next chapter.

Apart from studying the analyses conducted by Kerr (1999) and Smith and Keoleian (2004) the author developed and supervised an own analysis in cooperation with a colleague[17]. The actual analysis was conducted by four master students. Next section will describe the results from the analysis.

4.1.2 Refurbishing versus Recycling at Electrolux AB

The analysis was primarily an environmental comparison of two end-of-life scenarios for two household appliances. Electrolux often experiences that household appliances are being broken down during use or damaged during transportation. These broken/damaged appliances arrive to various service centres all over Sweden. In the first scenario the appliances are material recycled close to the service centres. In the second scenario (existing), the appliances are transported by heavy trucks and remanufactured in a facility in Motala, Sweden. The methodologies used were LCA modelling and ABC as earlier mentioned in Chapter 2. This analysis included both an environmental part and an economic part. The products that were analysed were a washing machine and a refrigerator (combined refrigerator/freezer). The two different scenarios of remanufacturing and material recycling are shown in Table 8 as well as the figures for new product manufacturing ('New Prod.'). In the scenario for remanufacturing the part going to material recycling is included. In this case the figure is 16,7 percent, i.e. 83,3 percent of the products coming to the remanufacturing facility are remanufactured and sold back to the consumer market. As 16,7 percent of the refurbished products are material recycled this share is accounted for and shown in brackets in Table 6. For example, for the first refurbishment estimation, 'non-renewable material (kg)', for the refrigerator the figure in brackets derives from: $1.4 + 0.167 \cdot 0.8 = 1.5$.

[17] The colleague referred to is Sara Tyskeng, Ph.D Student at Division of environmental technique, Department of mechanical engineering, Linköpings universitet

Table 6. LCA-model inventory results of a comparison of the remanufacturing, material recycling and new production of two different household appliances, a washing machine and a refrigerator (based on Hildén et al., 2003 and Paper V).

Functional Unit	Refrigerator			Washing Machine		
Scenario	Remanu-facture	Recycle	New Prod.	Remanu-facture	Recycle	New Prod.
Resources						
Non-renewable material (kg)	1.4 (1.5)	0.8	189.4	1.5 (1.5)	0.1	120
Renewable material (kg)	0.2 (0.2)	-	1.1	0.2 (0.2)	-	2.0
Energy (kWh)	20 (23)	16	1182	24 (24)	2.8	750
Emissions						
Greenhouse Gases (kg CO_2-eqvivalents)	2.5 (3.7)	7	214	2.4 (2.4)	0.2	160
Acidifying gases (mol H^+-eq)	0.0004 (0.2)	1.4	19.5	0.001 (0.01)	0.04	29.1
Ground level ozone gases (kg C_2H_4-eqvivalents)	0.002 (0.004)	0.009	0.004	0.002 (0.002)	-	0.1
Eutrophication compounds (kg O_2-eqvivalents)	0.2 (0.2)	0.3	14.3	1.3 (1.3)	0.05	2.5
Recyclable resources						
Materials (kg)	0 (12.7)	76.4	6.4	0 (7.5)	45.1	5.2
Waste						
Hazardous (kg)	0.003	-	0.23	0.002 (0.09)	0.5	2.0
General (kg)	1.1 (3.3)	13	160	1.3 (1.3)	0.1	198

For the washing machine, a high amount of transports in the remanufacturing scenario resulted in higher emissions of greenhouse gases. These emissions are 12 times higher than in the recycling scenario. On the other hand, the greenhouse gas emissions are more than 60 times higher for new production in comparison to remanufacturing. For the refrigerator, the Isobutane R600a and cyclopentane, used as refrigerant and cooling agent are taken care of in the refurbishment scenario which makes the recycling scenario worse considering the greenhouse gas emissions.

The differences in the life cycle inventory results between a refrigerator and a washing machine (Table 6) can be explained mainly by their weight difference and thus bigger emissions in the transport of a refrigerator. The acidifying effect of remanufacturing is smaller than that of recycling in the case of both the refrigerator and the washing machine. The usage of heavy machinery at the recycling facilities also causes emissions. The difference between the emissions of the remanufacturing scenario is again caused by the different weights of the machines. The release of ground level ozone gases is fairly marginal in both scenarios. This effect category has little significance in this research. Nitrogen and phosphorous compounds are the main causes of eutrophication. The usage of laundry detergents and washing agents in the test and clean-up phases of washing machines, explains the higher amount of eutrophication compounds released when being remanufactured.

When reading the results in Table 6 it is most interesting to compare remanufacturing with new production since the end product of those scenarios are more similar. An interesting comparison would be to have the recycled material be a part of a newly manufactured product; in that case, the remanufacturing and recycling scenario would be more comparable. If this were the case, more things, like transports from the local recycler to the manufacturing facility would be added. In the previously described analyses by Kerr (1999) and Smith and Keoleian (2004) the comparisons were between remanufactured and new manufactured products. This shows that the setting of system boundary is crucial for what results will be achieved.

All in all, from an environmental point of view, remanufacturing seems in this analysis to be a sound way to achieve functional products. The remanufacturing process results in a functional product, while recycling only provides material. A negative aspect, compared to recycling, is the need for longer transports as Electrolux has only one refurbishment facility in Sweden. By using sophisticated logistics in cooperation with transport companies, the amount of transports needed has been minimized. Energy consumption at the facility is fairly small, as most of the work is done manually.

In comparison to the production of a completely new product, the emissions and energy needs resulting from refurbishment are very small. The amount of energy needed to produce a new refrigerator is 50 times greater than the energy needed for refurbishment. The production of a new washing machine requires 30 times more energy than the refurbishment of such a product. Similarly, the need for material resources is much greater when producing completely new products. The usage of materials is becoming an important issue, as non-renewable resources are diminishing.

These results are in line with an analysis made by Electrolux that also shows that the emissions caused when refurbishing refrigerator are smaller than those generated in the recycling scenario. Furthermore, the Electrolux study had smaller system boundaries, which made this analysis more thorough. The energy savings according to Electrolux when remanufacture their products in Motala instead of manufacture new products, was the same amount as for warming of 250 houses yearly[18].

Parallel to the ecological calculations an economic analysis of the scenarios was conducted. It is clear that the refurbishment scenario results in more costs than the recycling scenario. One reason for this is that refurbishment is a value adding process and it takes significant efforts to add value to an old household appliance. The recycling process, on the other hand, only adds limited value to the product. The process just puts the appliance in a shredder and the different materials are sorted for recycling. One should also take into account that the refurbishment process generates an income and a positive environmental image for Electrolux. The refurbished products are sold to retailers and with the income from the retailers the costs that accrue in refurbishment can be covered with a good marginal. Depending on what kind of cosmetically flaws the refurbished appliances have they are sold to the retailers at a price range of 50 to 75 percent of the ordinary manufacturing price. The amount of overhead costs in refurbishment is considered high (about 70 percent), because the refurbishment process, for example, only uses spare parts that are disassembled from old products. Therefore, there are large storage areas for spare parts and products that are waiting for spare parts that are not in stock at that particular time. Despite these expenditures, the process for refurbishing household appliances was found profitable.

In the recycling scenario, costs were analysed on a higher level than in the first existing refurbishment scenario. A full scale working system for the systematic recycling does not

[18] According to unpublished calculations made by Gianluca Brotto, Electrolux AB.

yet exist. Therefore, the recycling scenario was analysed by conducting cost estimation. It was found that for recycling, the costs derived from transporting, collecting and recycling of the appliances. The main idea with recycling activities differs economically from the idea with refurbishment. For refurbishment there are really possibilities to get an income from the refurbished products, because they have quite a big economical value after the process. In addition, the refurbishment process adds value to the product, whereas the recycling process normally does not. In the recycling process, the products are shredded and recycled into different raw materials, which can then be reused in some different value-adding process.

Finally, when summing up the different results of the analyses, one can see that the studied and performed analyses show that remanufacturing is in general preferable to other end-of-life scenarios or new production from an environmental perspective, having in mind that the remanufacturing process results with a functional product. These results go in line with the end-of-life priority lists stated by Graedel and Allenby (1996) and Ryding et al. (1995) (see Section 3.4.2.). Furthermore, it was shown that the refurbishment of household appliances in the Motala facility was profitable as well as the study conducted by Smith and Keoleian (2004). One must also consider the value of reselling the product, environmental image, costs and loss of yield for new manufacturing (applicable if they are in the same market). These issues are further elaborated in the remanufacturing case studies described in Section 4.4. These results are also discussed in Paper I, V and VI.

4.2 The Generic Remanufacturing Process

The second research question aims at identifying the steps in a generic remanufacturing process. Again, as for the previous research question, this question is addressed by studying the work of other researchers in combination with own research. This is explained in more detail in the methodology chapter. In the theoretical foundation, several types of remanufacturing businesses are described (see Section 3.2.2.). Independent on the remanufacturing type conducted, the products need to run through a remanufacturing process that includes several steps.

According to experiences of study visits by the author, remanufacturing companies choose different sequences of executing the remanufacturing steps. For example, the cores could either be disassembled followed by inspection (e.g. error detection) or the inspection could be the first step, without first being disassembled. In research, the remanufacturing process often is described with the inspection step taking place after the cleaning and disassembling steps (see e.g. Steinhilper, 1998; Smith and Keoleian, 2004). This is not always efficient, however, e.g. if the product has fatal errors, it will be useless to remanufacture. In practice, a visual inspection for major defects is almost always performed as part of product sorting when products arrive at the remanufacturing facility. However, detailed inspections are easier to conduct when the product has been cleaned. Hence, every remanufacturing process is unique and it is always necessary to choose a strategy for efficient remanufacturing as well as one that matches the type of product being remanufactured. The steps in the remanufacturing process could therefore be arranged in a different order, or some steps could even be omitted, depending on the product type, remanufacturing volume etc. An example of how products are remanufactured in the remanufacturing plant in Motala is shown in Figure 21.

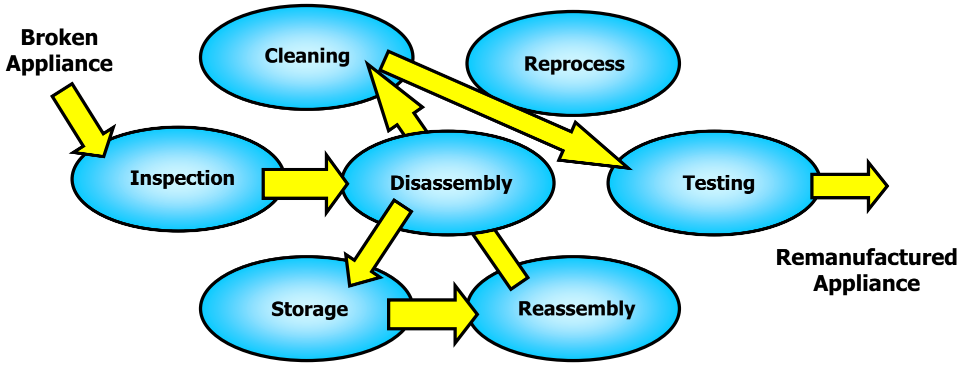


Figure 21. A step sequence of household appliance remanufacturing at Electrolux in Motala, Sweden.

In this example, the products are first inspected in order to locate the problem of the product. Secondly, broken parts are disassembled and the remains of the product are being stored. The product is then reassembled with new spare parts or spare parts from other products. Finally, it is cleaned and tested to ensure it works properly. The product is now remanufactured and ready to be shipped out to a retailer once again. Note that the repair step is omitted in this example since broken parts are replaced with new parts or spare parts. Another example, from Cummins OER, is shown in Figure 22.

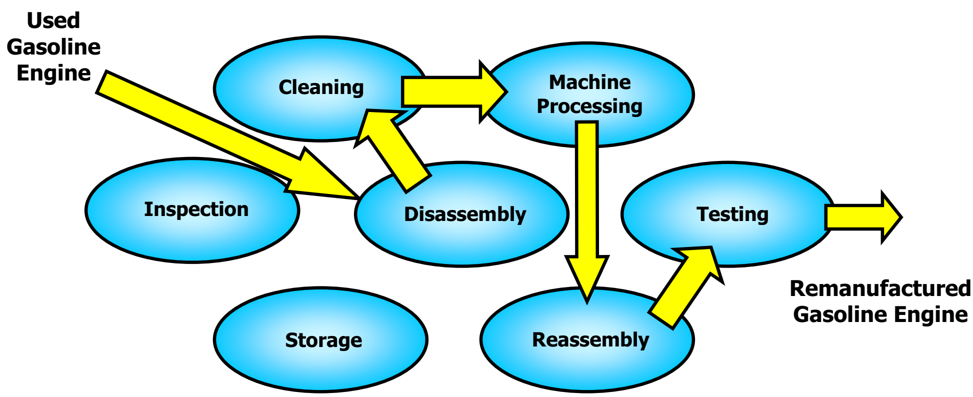


Figure 22. A step sequence of gasoline remanufacturing at Cummins OER in Toronto, Canada.

In the case of Cummins OER, the basic flow of remanufacturing starts with disassembly of the engine core into its various components, then it goes through a cleaning process where the dirt and the debris are removed. Several parts then go through a machining process where the engine is reprocessed to desired dimensions, and major sealings and surfaces are treated. Next, the assembly step follows where the engine's parts are reassembled. Finally, the engines are cold tested for compression oil flow, and leak down tested for water cavities.

These two cases show two different ways of arranging the remanufacturing steps. In these remanufacturing processes, internal transports and packaging of the products are not considered as remanufacturing process steps. In Paper II a generic remanufacturing process is described based on other researchers' results and by looking at the Electrolux facility in Motala. To verify and possibly refine the generic remanufacturing process further, six remanufacturing case studies were performed (also related to research question 4). Combining the literature study and the remanufacturing case studies we receive the following result of a generic remanufacturing process shown in Figure 23.

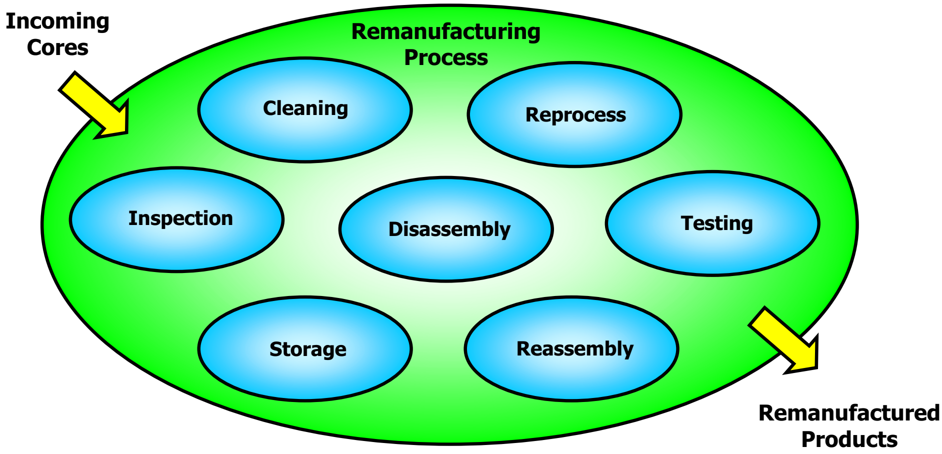


Figure 23. The generic remanufacturing process.

The step called 'reprocess' stands for machining processes, toner filling or whatever is needed as reprocessing in order to make the product functional again. This step is dependant on what kind of product is being remanufactured.

In many generic remanufacturing processes a specific step sequence is shown (see e.g. Steinhilper, 1998). In this model, see Figure 23, the possible steps are shown without any specific order. The sequence that the remanufacturing process has is dependant on many things such as; product design, working environment, volumes etc. These results are further discussed in Paper II and Paper VI.

4.3 Preferable Remanufacturing Product Properties

As a continuation of identifying the generic remanufacturing steps, it was a challenge to identify the preferable product properties for each step. Once again, previous conducted research and my own research conducted in Linköping were combined in order to address the third research question stated in Section 1.4. The research related to this research question is mainly described in appended Papers II, III and IV. All the product properties from the steps in the generic remanufacturing process (Figure 23) can be condensed into the following matrix (see Figure 24 below) of remanufacturing product properties - the Remanufacturing Property Matrix (RemPro).

Remanufacturing Step / Product Property	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Figure 24. The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps.

The RemPro-matrix illustrated above shows which product properties are preferable for the different steps in the remanufacturing process. The RemPro matrix could further be used as a design tool. Using this matrix, the designer can easily see what properties that are needed for the different steps; depending on which product is being designed, any step can be of particular interest and therefore emphasized. The RemPro-matrix can be used in, for example, the cleaning phase. In this case, the product parts should be 'easy to access' and the material should 'resist the cleaning solutions'. At inspection, on the other hand, it is important to easily 'verify what the product or product part condition' has. Furthermore, for the inspection step, it must be 'easy to identify' the parts and testing points, which should also be 'easy to access'.

It is important, though, to have the whole remanufacturing process in mind when designing products for remanufacturing. For example, single focus on one step could make other remanufacturing steps too difficult or expensive to carry out. One must remember that the essential goal in remanufacture is part reuse. If a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly will not be a factor (Shu and Flowers, 1998). This means that much effort can be made in product design without getting the expected benefits. As Shu and Flowers (1998) also declare, the reliability of the part is very important since it has to go through at least one life cycle, including all remanufacturing steps, and still work satisfactorily.

To conclude, this section has shown that there are many product properties to consider when designing a product for remanufacturing. The circumstances, such as product type, volume, remanufacturing system etc. must be considered, since they are important factors to consider when setting the remanufacturing sequence and determining which properties to prioritize. These aspects are further discussed in the next section.

Since the remanufacturing process includes many steps, there are some essential properties that the products need to have in order to be remanufactured in an efficient manner. When studying literature about remanufacturing processes and analysing the

Motala facility to find out what kind of product properties are important for the different remanufacturing steps, the following four properties were found to be most frequently important for products, and its parts:

- *ease of access,*
- *ease of identification,*
- *wear resistance* and
- *ease of handling.*

Theoretical studies and the case studies at Electrolux resulted in these product properties. The above stated properties provide the solution to the third research question stated in Section 1.4.

4.4 Results from the remanufacturing case studies

Addressing the fourth research question, a case study including six different remanufacturing companies was conducted. The case study methodology is described in the research methodology chapter, where, for example, the method for rapid plant assessment (RPA) is described. These case studies have not been published; instead the case study reports are included as Appendix A.

In this section the results from the individual case studies at the remanufacturing facilities will be described briefly. The results from the remanufacturing companies are described in the following order:

- 24 Hour Toner Services
- MKG Clearprint
- Cummins OER
- FUJI Film
- Scania CV AB
- Electrolux AB

These individual summaries of the case studies are followed by a cross case analysis according to the case study methodology described in Yin (1994). In the cross case analysis, the companies in the case study are compared and general results are described.

4.4.1 24 Hour Toner Services

The first case study was conducted at 24 Hour Toner Services, which is a small remanufacturer of toner cartridges in Toronto, Canada. It is a small family-run business and has one remanufacturing facility with 17 employees. The most important driving force for starting the business was, naturally, to gain a profit. A secondary driving force was to contribute towards stemming the flow of garbage going to landfills.

At the facility, toner cartridges are remanufactured, mostly from laser printers, photocopiers and fax machines. It is only the cartridges and some other parts for printers that are remanufactured. Currently the volume of remanufactured cartridges is 1300 a month but the goal is to reach 2000. The remanufacturing of cartridges has following step sequence:

1. Receive empty cartridges from customer
2. Disassemble
3. Clean
4. Separate parts
5. Toner refill
6. Reassemble
7. Test
8. Package

Rapid Plant Assessment

According to the questionnaire of 20 questions in the RPA-sheet, the number of yeses was 8 out of 20. Synthesizing these in the rating sheet, a leanness number of 55 was achieved. In the sheet, one can conclude that the company should improve the material flows in the process and the use of space. Other parts that need to be considered are the amounts of inventory and work-in-progress. Improving the integration of the supply chain can change much of these things.

Company analysis

The company has large storage areas, which are more costly and need to be reduced. Better knowledge about which and how many cartridges that are incoming could improve the process since the storage of spare parts could be adapted for incoming cartridges instead of having many spare parts for many types of cartridges. The current storage arrangements require too much space, considering both storage for the empties and storage for new spare parts. Furthermore, all parts that are put in storage hold capital for the company, which could be used more wisely.

A problem with this type of operation is that the original manufacturer competes on the same market by offering new cartridges. Having the same customers affects the design of the cartridges negatively from a remanufacturing perspective. Hence, the products are not designed for remanufacturing. If the OEMs had their own remanufacturing business, the cartridges would most likely have been adapted for remanufacturing. Now, when independent remanufacturers remanufacture cartridges to the same market, the cartridges are optimised for new manufacturing. Due to this, the customer ends up paying more for the remanufactured cartridge than actually would be needed.

Since volumes are rather low (16 000 cartridges per year) and number of products is high (160), it is of the utmost importance to have a flexible process. This is through the use of manual operators, who can perform every step in the remanufacturing process.

Cleaning and toner refill are the steps that allocate the longest time in the process. The company could prepare to buy a filling machine as suggested to improve at least the filling step. A second testing machine should be installed in order to speed up the process.

4.4.2 MKG Clearprint

The second case study was conducted at MKG Clearprint, which is a large remanufacturer of toner cartridges in Toronto, Canada. The incentive to start the business was for economic reasons. MKG Clearprint is not a part of a bigger company group and the facility in Mississauga is the only one of its kind. In good times there are 400 people working in the company. MKG Clearprint holds an ISO9002 certificate, which helps management to structure the quality management system at the facility. Environmental concerns are included in the company and although they do not use ISO14001. They are aware that their business is good for the environment, which is used as marketing in customer brochures.

At the facility, toner cartridges are remanufactured, mostly from laser printers, photocopiers and fax machines. Currently the volume of remanufactured cartridges is 240 000 annually. The remanufacturing of cartridges has following step sequence:

1. Receive and sort the empty cartridges
2. Analyse the cartridges
3. Disassembly
4. Reassembly and refill toner
5. Post testing
6. Tagging and bagging
7. Packaging

Rapid Plant Assessment

The question filled in the rapid plant assessment show 11 yeses and in the connected matrix (score: 65) it is only the part that deals with material flows, space use, material movement means that are below average. This implies that MKG should work with these issues and improve their remanufacturing process. Of course, there are other issues to consider, but above these mentioned above the are most important to deal with.

Company analysis

MKG Clearprint has relatively high product volumes (240 000 annually), which gives it good possibilities for using lines in its remanufacturing process. As the process looks today, it is largely station-based. The remanufacturing steps could be situated more closely together to avoid unnecessarily long transports. Furthermore, the steps of disassembly, reassembly and testing could be more streamlined with parallel flows for different kinds of products. This change would most probably increase the efficiency of the remanufacturing process. The operators need to go several times to the bench for disassembly/reassembly and the testing area before having the cartridge delivered to the following step.

Some parts are automated, which speeds up the workflow. Since there is only one machine performing the analysing before disassembly, MKG should consider investing in a second testing machine. The rest of the process is primarily manual, which makes the process highly flexible for the various kinds of products being remanufactured.

If the disassembly/reassembly steps are redesigned, MKG should also consider making working conditions better in the facility as well. Two suggestions are lowering the level of noise and letting the operators shift positions in their lines.

Putting the remanufacturing steps closer to each other while reducing the number of cartridges in storage would most likely make the process more efficient and lean.

4.4.3 Cummins OER

The third case study was conducted at Cummins OER, which is a large remanufacturer of automotive and non-automotive gasoline engines in Toronto, Canada. The main goal of this business is to make money and Cummins OER does this through remanufacturing. There are other considerations such as plant capacity of original engine manufacturing to provide capacity, hence they could utilize their equipment for new manufacturing and Cummins OER will provide the capacity through remanufacturing operation. Recycling of parts (remanufacturing) is a good thing to do from a business standpoint. Worldwide there are over 20 000 employees in both new and remanufacturing operations and within this facility there are 180-200 approximately focusing on non-Cummins products. The remanufacturing process at Cummins OER include following steps:

1. Disassembly
2. Cleaning
3. Machining process
4. Assembly
5. Cold test and other tests
6. Packaging

Rapid Plant Assessment

In the RPA, Cummins OER scored well in the categories of 'ability to manage flexibility and variability' and 'Quality System Deployment'. This might be the result of its long experience and demanding quality standards. On the other hand, the company scored poorly when it came to 'Product flow, space use & material movement means' and 'Inventory & WIP Levels'. Score: 57.

Company analysis

Cummins OER has dealt with remanufacturing for a long while (56 years) and is one example of a remanufacturing business that started during the remanufacturing boost that started during and after Second World War. The company is certified with quality and environmental standards, which can be noticed, in their remanufacturing process. For example, environmental issues regarding packaging, chemicals spills and processes are regarded.

The material flows are quite good since the process steps in the facility are laid out in a logical sequence. The level of storage is little bit too high, especially since the first part of the process (disassembly-cleaning-machining) is performed separately from the second part (assembly-test-packaging). With the first part more station-based than the latter part. Furthermore, the machining process includes some parallel flows using two assembly lines, which, in turn reduces the possibilities for these steps to be bottlenecks in the process.

The company has a strong relationship with manufacturers since they are both Cummins OER suppliers and customers. The remanufacturing process at Cummins must follow the requirements of the manufacturers. The cleaning step could be improved, since it is most labour intensive and takes the longest time. Further, more component machining has a great deal of consumable supplies and capital investment, which makes it more costly. Machining and assembly are two steps that have high labour costs and which might be reduced..

4.4.4 Electrolux AB

Electrolux AB began to remanufacture their products in a facility in Motala, Sweden in 1998. The driving force for this facility was mainly environmental, although economical benefits for the company, retailers and the market (consumers) were also important. Furthermore, functional sales worked as a potential driving force to start the remanufacture of products. Since earning a profit from these activities was uncertain from the start, it was decided to put the remanufacturing process in a seldom used warehouse near an ordinary manufacturing plant for stoves.

Since the remanufacturing process is showing profit and this adds up to the company's environmental profile the facility is still in operation with increasing volumes. At present, 7 500 products are arriving at the Motala facility annually from all over Scandinavia. Only 5 500 of the incoming cores leave the facility as refurbished. The rest, 2 000, are being used for taking spare parts from or being material recycled since they are in such bad shape or due to low market demand.

Most of the products that arrive at Motala are relatively newly manufactured but have failures covered by warranties and which the servicemen have not been able to repair at the customer. Moreover, products that have damage from transport and products used for leasing are also remanufactured at the facility. Once the products arrive in Motala, they are registered into a database, after which they will follow a standard set of procedures:

1. Test and safety control
2. Exchange of components and repairs
3. Clean-up (outsourced to a cleaning professional)
4. High voltage test
5. Marking with new serial number
6. Packaging the product

Rapid Plant Assessment

The answers to the RPA questionnaire show 10 yeses, while the rating sheet total was 57. Most of the categories in the rating sheet were marked around average. The RPA shows that Electrolux has good quality on their refurbished appliances, although they have high levels of inventories. Since the inventory space rent is rather low, this is not considered as a high cost, and not of importance to reduce. The work force is motivated and committed to quality.

Company analysis

The refurbishing facility that Electrolux operates in Motala is rather young. Although it is labour intensive and has relatively small remanufacturing volumes, it is showing profit. According to the facility manager, it would be more profitable to have this operation in a country with lower salaries. Today, there are many inexpensive appliances on the market, which remanufactured appliances from the facility compete with. Cleaning is the remanufacturing step that needs to be improved the most according to the data collected. To increase efficiency in this step, the following actions can be taken:

- Install steam cleaning.
- Train personnel so that they become more task-flexible, i.e. personnel from other work areas can ease the cleaning step by doing some kind of pre-wash when needed.
- Design products that do not collect dirt in the first place.

Many of the steps can be facilitated through improved product design. In some cases, more effort to adapt the product for remanufacturing, could be of value, instead of making changes in the process. As it looks today, the personnel are flexible and have good knowledge of how to repair many different types of appliances. There is also a high degree of flexibility due to the storage capacities in the facility, which the facility manager uses for the seasonal changes in demand.

Although there is a database of the products in storage, there are no records of which spare parts are held in stock; this information is only in the heads of the remanufacturing personnel. This could be a problem when the staff is sick or when remanufacturing volumes increase. Today, however, this situation is not a problem.

The refurbishment operation is good for Electrolux since it contributes to the company's environmental image, and shows profit. Furthermore, many appliances that earlier could not be repaired on site are now refurbished and sold to retailers once again. This option of end-of-life treatment is one of the best possible for an appliance company as Electrolux.

4.4.5 Scania CV AB

The second Swedish case study was performed at Scania CV AB. Scania's disassembly facility in Hovsjö is relatively new and was opened in January, 2003. There were two reasons why Scania started this business: The first was due to pressure on the company to adapt its organization to comply with forthcoming legislation regarding extended producer responsibilities. Secondly, there were people within the company that were experienced in the disassembly area. The facility is located nearby Scania's ordinary manufacturing facility in Södertälje, Sweden. At the studied facility in Hovsjö, Sweden, heavy trucks are disassembled and the parts are sold rather than reassembled. Scania chooses not to reassemble the heavy trucks since it would compete with their new production.

During the first year of operation 150 heavy trucks were disassembled, of which 80 percent have the Scania brand and the other 20 percent are Volvo heavy trucks.
The goal is to disassemble 150-200 heavy trucks per year. Trucks are mostly bought from Scania's purchasing department or from insurance companies. Truck sellers are calling in 20-30 times a day. The disassembly process is manual and includes the following steps:

1. The purchaser purchases the truck (from Scania's purchase department or from insurance companies)
2. The purchased truck is transported to the facility via a contracted towing company.
3. A standard test is performed on the vehicle and a protocol is written including for example, how the engine sounds and what possible malfunctions may be present.
4. The test results are entered into a database together with the details of the truck's type of use, mileage, purchasing price, and manufacturing year.
5. The truck is transported to one of the facility's disassembly areas where it is disassembled using standard equipment.
6. The truck is emptied on liquids such as glycol, oil, and diesel.
7. Parts with high value (around 50 percent) are put in the database with a unique product number. There are three levels of storage of these parts: Parts, complete engines and chassis, and coachwork. Many of the parts are cleaned before put into storage although certain parts are not in order to prevent rusting of the parts.
8. The diesel is reused and the parts that are not put in any of the three above mentioned storage areas are recycled into several material categories.
9. Finally, the refurbished parts are sold to any of Scania's retailers

If the trucks are older than older than 10 years only a few parts are refurbished and sold, such as the motor, gear box and back gear. These old trucks only take a day to disassemble in comparison to the newer truck, which take up to a week to disassemble. In these cases more of the truck is saved and sold.

Rapid Plant Assessment

In the RPA, Scania scored well in the areas of managing flexibility, customer satisfaction, quality and team work. The work force is very flexible and can chose to disassemble any kind of truck that needs to be disassembled at the moment. The process is totally manual and the work at the three disassembly areas is carried on independent of each other. Scania got lower scores for product flow, inventory levels which can be related to the type of business and low remanufacturing volumes. Furthermore, the product being remanufactured, in this case, trucks are quite complex and high volumes are hard to achieve. The total RPA score for the facility was 57.

Company analysis

Scania is an original equipment remanufacturer, which uses the knowledge of the other parts of the company. Designers have been evaluating the own designs in the disassembly process. The collaboration is not used in full since the trucks are not reassembled. This is due to the fact that Scania does not want to compete with remanufactured trucks on the same market as their new manufactured trucks. As the products looks today they are relatively easy to manufacture. Changes have been done over the years and Scania's modularise thinking works well for the disassembly process. The most time consuming parts of the process is the disassembly. High labour costs make this part relatively expensive. The disposal of materials and liquids is a part that gives high costs. The bottleneck in the process is that there are only three disassembly areas to disassemble at which reduces the possibilities for higher volumes. There are plenty of cores to buy and the amount of customers is rising. The database for remanufactured products will grow and the personnel are making it easier to buy the remanufactured parts.

4.4.6 Fuji Film

In 1990 FUJI Film began to manufacture single-use cameras. It became a very popular product, and was subsequently mass-produced. The nature of these products is that they are often returned to the photo shop in order to have the photos developed. This nature of the single-used cameras led to the accumulation of numerous used cameras at the photo shops. During this time, there was also an increase in environmental awareness, and criticism was directed towards the single-use cameras, since their batteries were used only once. FUJI Film then realised that they needed to take responsibility for collecting and recycling their single-use cameras.

All of the four manufacturing facilities in the Ashihagara area hold ISO9001 and ISO14001 certifications. There are around 250 employees at the Ashihagara area and 50 of them work in the remanufacturing facility. The production volumes for single-use cameras were in 2004 approximately 60,000,000 annually. Out of these, 60 percent were produced in the remanufacturing facility, i.e. 36,000,000. Internationally, FUJI Film has other remanufacturing facilities: two in Greenwood, South Carolina, USA and one in Kleve, Germany. These, however, do not have the same level of automation as the Ashihagara facility. Within the FUJI company group, there is also FUJI Xerox, which remanufactures fax machines. Once the products arrive to Ashihagara, they will follow a standard set of procedures:

1. Sorting
2. Disassembly
3. Cleaning
4. Inspection
5. Repair
6. Assembly
7. Inspection
8. Packaging

Rapid Plant Assessment

No RPA was conducted since there was no possibility to observe the actual remanufacturing process in detail and due to time constraints.

Company analysis

The remanufacturing process is highly automated, which affects many parts of the business. The high volumes provide a good driving force for automating the process. High volumes also put requirements on the product design. FUJI Film has made a good compromise between adapting products for remanufacturing and selling new types of designs. Their ‘unit design’ seems to work well for both driving forces.

A problem in their process seems to be the testing of the flash unit. The company should look over its internal part design to make it more adapted to their processes, and the testing of the flash unit could possibly be facilitated. Furthermore, the reverse logistics are important when dealing with these large volumes, and it has been brought up as a crucial area that needs to be addressed. As a part of the reverse logistics, the large numbers of cameras in the warehouses and at the remanufacturing facility are important. The storage of cameras at the remanufacturing facility works as a buffer for evening out seasonal differences. Since FUJI Film has good control over how these changes in volume look like, the remanufacturing volumes could be adapted seasonally and the number of cameras in the buffer storage could be reduced. If this change is possible, or what effect it could have on the business, is unknown.

4.4.7 Cross Case Analysis

In this section, the companies are compared and general results are described. An interesting fact found in the case studies was that the reasons to remanufacture were of different origins. The manifold of driving forces can be shown by following three examples. Toner cartridge remanufacturers in Canada have market demand as their strongest driving force while remanufacturers in Sweden, which have a steady flow of discarded products, have legislative driving forces of paying the remanufacturers to take care of their manufactured products (e.g. Swedish manufacturers have to follow the product take-back laws and thus remanufacturers/recyclers are supplied with their end-of-use products.) In Japan, on the other hand, a strong driving force for remanufacturing of single-use cameras is partly of environmental origin. This is due to the fact that used single-used cameras ends up at retailers and needs to be taken care of. This is also seen as a good opportunity to improve the environmental image of the company. All of these companies have economic benefits as direct or indirect driving force for its remanufacturing business. Although it is interesting to compare the companies with each other, some general conclusions can be drawn.

- The uncertainty of how many and when the cores come to the remanufacturing facilities is a problem for many of the analysed companies. This makes the planning of the remanufacturing harder.
- The remanufacturing companies often have a high amount of cores, spare parts or half-finished products in storage, awaiting customers or spare parts. This binds much space and capital within the process.
- Cleaning and Reprocessing (repair) are a crucial step at three of the companies (24 Hour, Cummins and Electrolux)
- Inspection is a crucial step at two of the companies (MKG and FUJI Film)

Table 7 shows a list over the companies being analysed. The total RPA score from the RPA scoring sheets are very similar going from 55 to 57 excluding the score for MKG Clearprint, which has a score of 65.

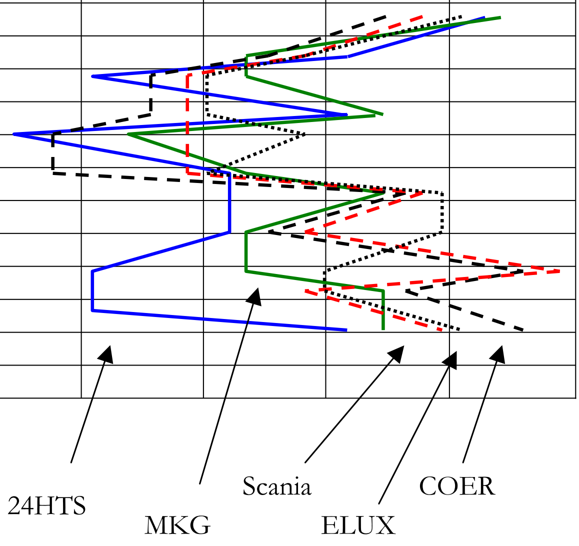
Table 7. A comparison between the analysed companies.

Company	Product	Type[19]	Volume	RPA
24 Hour T S	Toner Cartridges	Independent	16 000	55
MKG Clearprint	Toner Cartridges	Independent	240 000	65
Cummins OER	Gasoline Engines	OER/Contracted	Confidential	57
Scania CV AB	Diesel Engines	OER	150	57
Electrolux AB	Household Appliances	OER/Contracted	5 500	57
FUJI Film	Single-use Cameras	OER	36 000 000	-

It is hard to draw any conclusions from Table 7 rather than that one company seem to be more efficient (from a lean perspective) than the others. This could have to do that MKG Clearprint holds an ISO9001 certificate and have a high volume of remanufactured products that makes it easier to be efficient and the cartridge types being remanufactured are rather similar. Instead of only looking at the aggregated RPA-score it is, at least in this study, more interesting to compare the RPA scoring sheets viewed in Table 8 below.

Table 8. RPA scoring sheets for the analysed companies.

Ratings	Poor	Below A	Average	Above A	Excellent
Measure					
1. Customer Satisfaction					
2. Safety, Environment and Order					
3. Visual Management System					
4. Scheduling System					
5. Space use, Mtrl movement etc.					
6. Levels of Inventory and WIP					
7. Teamwork and motivation					
8. Cond. & maintenance of tools					
9. Mgt of complexity & variability					
10. Supply chain integration					
11. Commitment to quality					
Totals					



In general there is a low score on the measures 3, 5 and 6 which represents: Visual Management Deployment (3), Product Flow, Space Use and Material Movements (5) and Inventory and WIP Levels (6). Furthermore, there is a high score on the measures 1, 7, 9 and 11 which represents: Customer Satisfaction (1), People Teamwork, Skill Level and Motivation (7), Ability to Manage Complexity and Variability (9) and Quality System Deployment (11).

[19] See chapter 3.2 for description of the various types of remanufacturers.

Specific for the branches one can read that Toner Cartridge remanufacturers (24HTS and MKG) scores higher than other on measure 4 (Scheduling system) and lower than others on measure 9 (Ability to manage complexity and variability). Engine remanufacturers score higher then other on measure 9 (Ability to Manage Complexity and Variability). Electrolux is better than the others at measure 5 and 8, which represents Product Flow, Space Use and Material Movements and Equipment (5) and Tooling State and Maintenance (8). For the branches of engine and toner cartridge remanufacturers it seems that higher remanufacturing volumes give a higher overall score (i.e. the graph is more to the right).

To summarise this section, one can see that there are some general issues for the remanufacturing firms to improve in order to achieve a more leanness/effectiveness. The RPA ratings did not say much but looking at the RPA sheets some interesting results were found. Although there are only five remanufacturing companies RPA-analysed in this case study, one can see in the picture above that the remanufacturing process have similar graphs within the same branch.

4.5 Integration of DfRem aspects into EMSs

The fifth and last research question deals with how the integration of design for remanufacturing (DfRem) aspects could be better integrated into a company's environmental management systems (EMSs). As described in the methodology a wider scope was taken to address this research question. Instead of only looking at aspects of DfRem, which could be seen as a part of DfE, all aspects of DfE were considered. This section briefly describes the results from this investigation, which is described in more detail in Paper VII and Paper VIII.

This research project[20] started off by conducting a literature study (see Paper VII) of what the experiences of DfE integrated into EMSs were. These kinds of EMSs are, in research, sometimes called product oriented environmental management systems (POEMS). As a result of the literature study, external auditors were found as key persons for the DfE integration. Hence, the external auditors were studied more closely in order to identify their role of integrating DfE and EMS.

4.5.1 Experiences found from the literature study

A cursory study of different POEMS models, e.g. models presented by Cramer and Alders (1999), Karlsson (2001), Klinkers et al. (1999), Rocha and Brezet (1999), and Rocha and Silvester (2001), show that they are quite similar on a general level. However, different terminology is used and the categorisation of what belongs in the different steps in the PDCA[21] cycle varies. On an overall level, and based on the references cited above and the authors' own experience, the following general steps of most of the product-related parts of a POEMS model can be stated as the PDCA cycle shown in Figure 25. The described process is mainly focused on the first implementation of a POEMS, which could be carried out by companies with or without an existing EMS or other management systems.

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[20] The research project was cooperation between Jonas Ammenberg and the author.

[21] The general PDCA cycle is described earlier in Section 3.4.3.

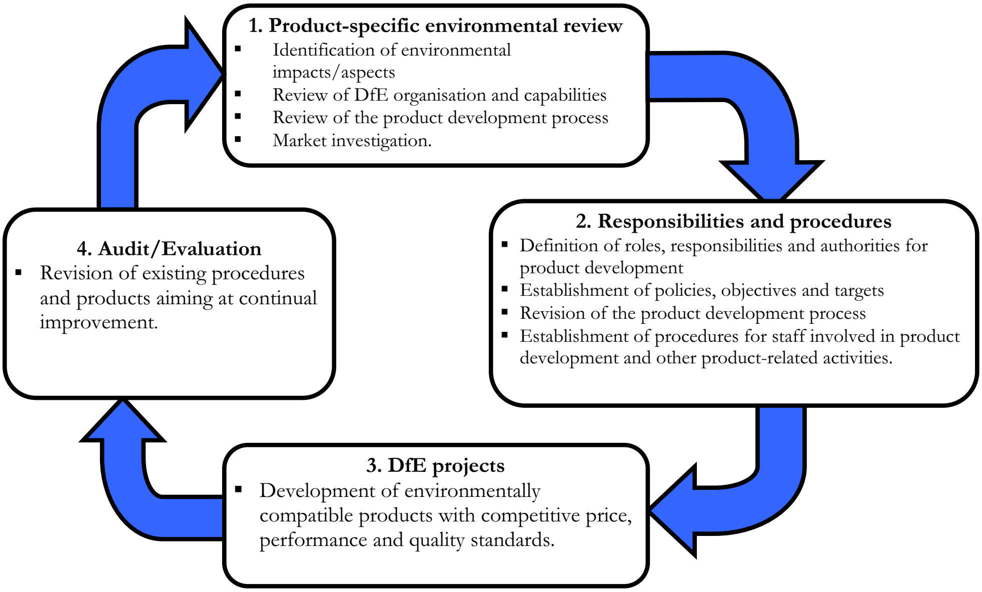

Figure 25. A POEMS model (Paper VII).

During the investigation it was found that research findings of the outcome of POEMS are scarce. Hence, it is hard to draw any general conclusions of the effects of POEMS. Based on case studies, it is known that POEMS projects driven and supported by, for example, consultants may be fruitful.

Studies of normal EMS show that researchers have different opinions concerning to what extent EMS encompass and affect product issues. Some research results bear witness to the fact that DfE and EMS activities are integrated in reality, while other findings indicate that the link between DfE and EMS is weak.

To what extent companies are willing and can manage to integrate DfE aspects into their management systems is dependent on many different factors. It appears reasonable to assume that what is an important factor for DfE or EMS individually is also important concerning their integration[22]. Accordingly, success factors, drivers and barriers that have been presented in literature as important for either one of the concepts have been gathered and categorised into four different levels, as shown in Figure 26. The ingredients of each level are further described and discussed in Paper VII, all affecting to what extent DfE and EMS are integrated and/or the outcome of such integration.

[22] No comprehensive literature on important drivers and barriers for POEMS has been found.

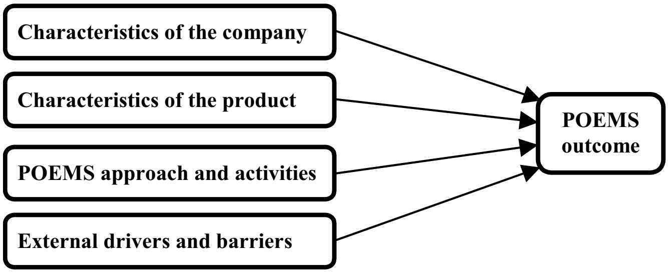

Figure 26. Four levels of important factors influencing to what extent EMS and DfE activities are integrated and/or the outcome of such integration, based on (Rocha and Silvester, 2001).

From a theoretical and environmental standpoint there are strong incentives to integrate DfE principles into standardised EMS (see further description in Paper VII). DfE-thinking could enrich EMS by contributing to a life-cycle perspective, helping the organisation to identify the most important flows of materials and energy upon which to focus. From a societal environmental perspective, many pollution problems related to specific sites (point sources) have, to a large extent, already been solved or clearly reduced. Instead, environmental impact caused by the consumer market, e.g. in the form of diffuse emissions[23], stands out as vital.

Consequently, from an environmental point of view, EMS covering a wider scope would be preferable and make EMS a more useful tool when striving for a sustainable development. On an organisational level, integration of DfE and EMS could foster better relations with stakeholders, at least those actively involved in the supply chain. The integration could also improve internal co-operation among members of different departments. At the same time, EMS may be useful to make DfE efforts become more permanent, i.e. lead to consistent and systematic DfE activities. Based on today's situation, it seems appropriate to picture the desired integration as divided into two parts. The first part concerns the integration of environmental aspects into the product development process[24], while the second part relates to the integration of the product development process into the management system of a company.

External environmental auditors and environmental consultants have important roles in this arena, since they could function both as a driver and a barrier for the integration of standardised EMS and DfE concepts (see e.g. Karlsson, 2001 and Ammenberg et al., 2001). However, Paper VII points out many important factors apart from EMS that must be adjusted as well, to reach improvements in environmental performance. The literature study (Paper VII) was complemented with the study of the role of external auditors (Paper VIII), of which the results is described in following paragraphs.

4.5.2 Experiences from external EMS auditors

The significant environmental aspects are the foundation stones around which the EMS is built. Consequently, to a large extent, the environmental effectiveness of these systems depends on the extent to which products and product-related aspects are classified as

[23] Diffuse emissions are for example CO_2-emissions, which cannot be controlled like an oil leakage in a factory.
[24] See chapter 3.3.4. Design for Environment.

significant. The answers relevant to this issue indicated that issues concerning the whole product seldom are judged as significant aspects and sometimes they are not considered as environmental aspects at all. This means that attention is seldom paid to product characteristics such as resource demands during the use phase, impacts during the end-of-life phase, recyclability, etc.

However, incoming goods and energy normally appear to be among the environmental aspects, which is positive. For instance, a few of the auditors emphasised that companies improve their purchase procedures and handling of chemicals. Nevertheless, many answers also revealed that the requirements posed to suppliers sometimes tend to be very weak; this appeared even worse concerning information to customers. One important issue clearly is the companies' possibilities to influence the life-cycle phases after the manufacture. To ensure that the most important flow of materials and energy are included in the EMS, the standard requirements, or at least their application, should be altered so that product issues are always regarded as environmental aspects[25].

The assessment of environmental aspects is a more delicate question. It is worrying that product aspects seldom are judged as significant and that some companies are reluctant to assess product aspects as significant. Generally speaking, many important resource flows are clearly connected to the products, which is why, according to the existing standard formulations, they ought to be considered as significant aspects. A problem is that the standard does not, and probably cannot, define the scope of an EMS and inform on how to weight aspects that exist along the life cycle.

Concerning the complete EMS, an absolute majority of the auditors stated that they are focused on a specific facility. This means that a dominant part of the EMS activities and procedures apply to the certified site. To what extent these activities and procedures are based on a life-cycle perspective, and are complemented with EMS parts that are focused on other phases in the life cycle, varies. The auditors' views ranged from allowing a narrow perspective to demanding a more holistic approach.

Commonly mentioned bottlenecks are complicated tools, difficulties in receiving useful information and lack of resources in terms of staff and competence. An important comment was that legal requirements steer companies towards a site-oriented perspective. It is unfortunate that many EMS seem to have a narrow scope. It would be advantageous if EMS could cover a wider perspective, since legal requirements and authority control to great extent focus on the facilities. Seen from a societal environmental perspective, many pollution problems related to specific sites (point sources) have been solved or clearly reduced. Instead, environmental impact caused by the consumer market, e.g. in the form of diffuse emissions, stand out as vital. Consequently, from an environmental point of view, EMS covering a wider scope would be preferable and make EMS a more useful tool when striving for a sustainable development.

A majority of the auditors said that they have great possibilities to strengthen the connection between DfE and EMS. Only a few of them asked for tougher standard formulations regarding products, while others wanted clarifications rather than stronger requirements. Judging from these impressions and comments, it is a hot issue concerning

[25] This applies to manufacturing companies.

to what degree auditors are allowed to function as consultants. Many interviewees spontaneously mentioned that they transfer information to companies that are not competing.

To strengthen the connection between DfE and EMS, customer demands seem to be of crucial importance. This includes consumers as well as business customers. Large multinational companies were mentioned as important actors within this field, since they have a big influence on smaller suppliers. Other areas mentioned were included better legislation and increased competence and knowledge.

4.5.3 Comparison of the auditors

To illustrate how the auditors' opinions vary and to verify how some of them almost consistently pose tougher requirements than others, a simple test was conducted. For five important areas the answers were compared and classified into one of three groups, in accordance with which is more preferable from an environmental point of view. The five areas concerned (the three groups are within parenthesis):

- **To what extent products are considered as significant environmental aspects**
  (often; it depends; seldom)
- **If environmental considerations are required in product development**
  (yes; I try to influence; no)
- **What these requirements encompass**
  (life cycle; it depends; site)
- **The scope of EMS**
  (site + other important parts; first site, then life cycle; site)
- **What kind of improvements are required to be reached**
  (operational; ok with organisational; don't know)

Figure 27 below illustrates the variation of responses from the auditors. It was surprising to see the difference between the auditors' responses. Only one auditor ended up in the same category for all the questions. All the others' shifted between the different groups, i.e. from preferable opinions to standpoints less advantageous for the environment. This is further discussed in Paper VIII.

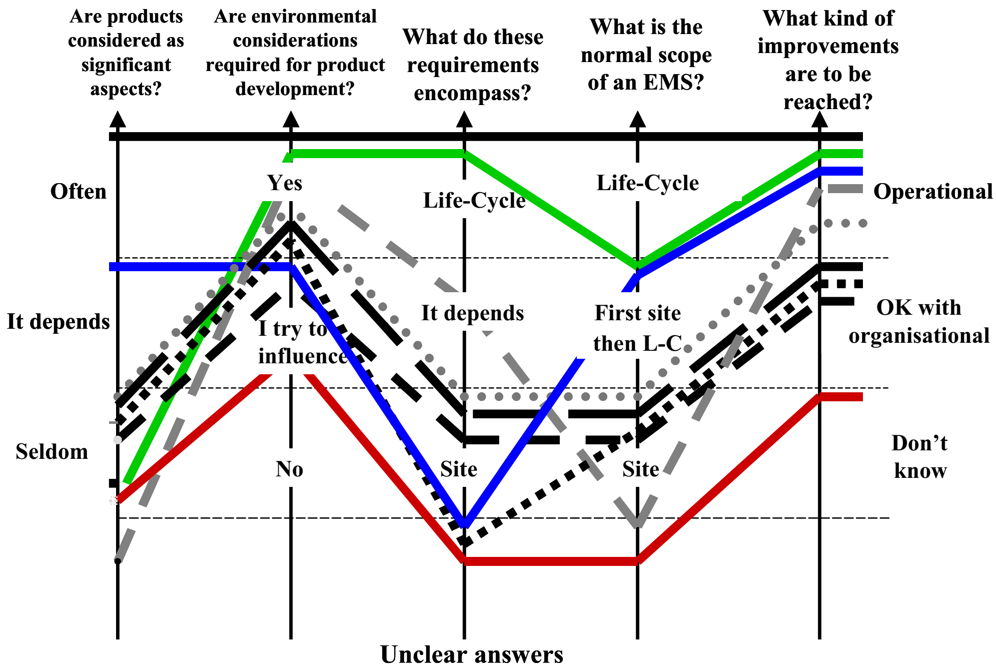

Figure 27. Distribution of the answers to five important questions. Each line corresponds to one auditor.

This finishes the research result chapter addressing all five research questions. The results can be further studied in the appended papers and in the remanufacturing case studies in Appendix A. The next chapter describe the discussions and conclusions of this dissertation.

5 Discussion and Conclusions

In this chapter, the results from the appended papers are summarised with new conclusions and perspectives drawn from the theoretical foundation. The chapter starts with a short introduction followed by discussion and conclusions of the results addressing the five research questions stated in Section 1.4. Finally, a critical review of this research is described and some suggestions for further research presented.

5.1 Introduction

As described in the theoretical foundation there are several benefits of remanufacturing, see e.g. Jacobsson (2000), Lund (1996), Steinhilper (1998), Bras and Hammond (1996). However, to achieve these benefits and make the remanufacturing efficient, the remanufacturer must consider reducing the obstacles and constraints that are related to remanufacturing, see e.g. Guide Jr. (2000), Geyer and Jackson (2004) and, van Nunen and Zuidwijk (2004).

The objective of this dissertation was ***to explore how product and process design can contribute to successful remanufacturing and to explore the integration of design for remanufacturing aspects to the environmental management systems of manufacturing companies***. The objective can be accomplished by addressing five research questions. These five research questions were emphasized since the objective is wide. The five research questions, as previously stated, were:

1. **Is product remanufacturing environmentally preferable in comparison to new product manufacturing and/or material recycling?**
2. **What steps are to be included in a generic remanufacturing process?**
3. **Which product properties are preferable for the remanufacturing steps?**
4. **How can remanufacturing facilities become more efficient?**
5. **How can design for remanufacturing aspects be integrated into manufacturing companies' environmental management systems?**

The results previously described in Chapter 4 are further discussed in the following section in chronological order starting with research question one.

5.2 Discussion of the research results

The first research question was:

1. **Is product remanufacturing environmentally preferable in comparison to new product manufacturing and/or material recycling?**

Environmental researchers that discuss end-of-life scenarios for products often put remanufacturing as one of the most preferable alternatives. With product remanufacturing, the geometrical form of the product is retained and its associated economic value is preserved. If the products also are adapted for remanufacturing, there are more environmental benefits achievable (see e.g. Kerr, 1999). The three environmental analyses referred to in this thesis (Kerr, 1999; Smith and Keoleian, 2004; and Paper V) show that remanufacturing of the studied products is in general the environmentally preferable option, considering use of materials. This is valid when remanufacturing is compared to recycling the product's material and/or by replacing it with a new manufactured product. However, the preferable end-of-life scenario for specific cases is often dependent on the remanufacturing context (e.g. which product type or which technology that is available). It is important to note that the figures for the Xerox Australia study (Kerr, 1999 also described in Paper I.) represent the savings in resource productivity during the manufacturing and disposal phases. To explain further; as photocopy machines are energy and resource intensive during the user phase, this is where the majority of the environmental burden is generated. Consequently, when aggregating the environmental performance of remanufacturing with those generated during the user phase, the savings, in percentage, of remanufacturing are less than if only the manufacturing phase would be considered. Although this indicates that proportional life cycle savings of remanufacturing may be less for products with high-energy intensity during its user phase, the benefits cannot be neglected. From a resource productivity point of view, remanufacturing still produces benefits for different levels of energy intensities during the user phase.

These issues were also discussed by Smith and Keoleian (2004). In their study, the significance of functional equivalency between new and remanufactured engines was explored. The analysis of potential differences in fuel efficiency between the two engines demonstrated the criticality of this parameter. A one percent improvement in fuel efficiency for a mid-sized automobile powered by a remanufactured engine could double the savings in life-cycle energy, whereas a decrease in efficiency of one percent would negate the benefits provided by the remanufactured engine through avoided materials production and manufacturing (Smith and Keoleian, 2004). Hence, the technology of the new product, as compared to the remanufactured product, could have high importance on the environmental impact. Parameters like the fuel efficiency described above can alter the results much by only small efficiency parameter change. In order to avoid these technology conserving aspects of remanufacturing, the products should be easy to upgrade to latest technology.

From a material resource perspective it has been showed in this dissertation that remanufacturing is a preferable scenario to replacement with a newly manufactured product. However, from an overall environmental perspective it is not clear that remanufacturing is a preferable option since it may lead to higher amount of emissions deriving from e.g. the amount of transports required for the remanufacturing process.

2. **What steps are to be included in a generic remanufacturing process?**

This question was addressed through results from empirical studies and results found in literature. In Paper II, a generic remanufacturing process was described based on empirical studies at the Electrolux facility in Motala and other researchers' results. The combined results were verified by studying six remanufacturing case studies (Appendix A). The generic remanufacturing process was refined after the verification. After the refinement, the generic remanufacturing process was identified as including the following remanufacturing process steps shown here in Figure 23 but also in previous chapter in Figure 28.

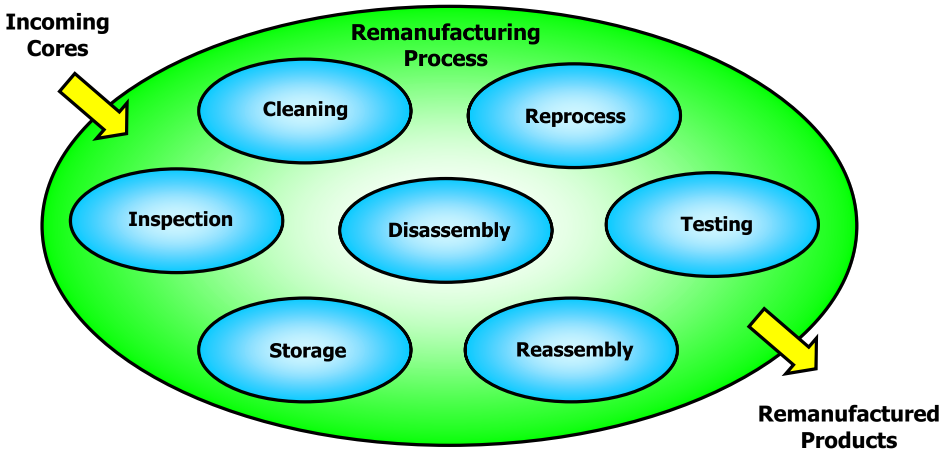

Figure 28. The generic remanufacturing process.

The reprocess step represents the step in the process where the core is machine processed (e.g. Cummins OER), refilled (e.g. MKG Clearprint), etc. to make the product functional again.

The sequence, in which these steps are performed, varies among the remanufacturing facilities. This is due to differences in context e.g. product design, remanufacturing volumes, and process layout. In some remanufacturing facilities some of these steps are even omitted. Many researchers have described the generic process as being a specific remanufacturing step sequence, but this is avoided in this research due to the amount of variations in step sequences. Developing a generic process all possibilities of sequences should be included. Some remanufacturers can even have different types of products remanufactured in different remanufacturing step sequences. The generic process in this dissertation includes those possibilities.

3. **Which product properties are preferable for the remanufacturing steps?**

When adapting products for the remanufacturing process all of the steps should be considered. For example, if one step such as reassembly is very difficult to perform on a product, it does not matter, in remanufacturing aspects, how much effort that has been put into adapt the product for disassembly. This research has identified many properties to consider when designing a product for remanufacturing. The circumstances, e.g. product type, volume, remanufacturing system etc. must be considered since they are important factors to consider when choosing remanufacturing sequence and determining which properties to prioritize.

Since a remanufacturing process often includes many steps, there are some essential properties that the products must possess in order to be remanufactured in an efficient manner. When analysing the Electrolux remanufacturing facility in Motala and studying the literature about remanufacturing processes, several product properties was elucidated as important for the different remanufacturing steps. The following four properties were found to be most frequently important for remanufactured products and its parts:

- ease of access
- ease of identification
- wear resistance
- ease of handling

These affected the ease of remanufacturing in several steps, see the RemPro-matrix in Figure 29 also illustrated in Figure 24 (Section 4.3). The above stated properties provide the answer to the third research question.

As a part of the remanufacturing case studies conducted in Canada, Japan and Sweden (see Appendix A), the generic remanufacturing process was verified. Furthermore, the results from the case studies could be used in combination with the RemPro-matrix. In the case studies it was shown that following three remanufacturing process steps were most crucial; Inspection, cleaning, and reprocessing. To facilitate these steps, RemPro-matrix shows that the designers should focus on giving the products the following properties; ease of access and wear resistance, since these are important for both the steps of cleaning and reprocessing. After this the designer should prioritize the properties; ease of identification, ease of verification, ease of handling and ease of separation since these also are included as preferable for the crucial steps but not to the same extent.

Remanufacturing Step / Product Property	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Figure 29. The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps.

If a company is considering to start a remanufacturing business, it could first investigate which steps those are crucial for the specific remanufacturing business area, e.g. engines, and thereafter try to facilitate both their products according to the RemPro-matrix as well as put in effort in making the crucial steps in the remanufacturing process as efficient as possible. By doing so, many obstacles could be reduced and the remanufacturer would have an advantage over its competitors. One should although have in mind that the RemPro-matrix has not yet been tested as a design tool at companies.

4. **How can remanufacturing facilities become more efficient?**

To address the fourth research question, remanufacturing case studies were performed at facilities in Canada, Japan and Sweden (see Appendix A). The business performance at the individual remanufacturing facilities relies much on the product characteristics and how their remanufacturing system works in relation to their stakeholders.

Furthermore, a challenge for the remanufacturing companies in the study was how to deal with reverse logistics. In many cases, the remanufacturer had limited knowledge of what cores come to the facility, in what amount and in which condition (see. e.g. Smith and Keoleian, 2004; and Geyer and Jackson, 2004). These uncertainties often cause problems for the remanufacturers. Some of them use core buffers to stabilise the flows in the remanufacturing process (e.g. Electrolux and FUJI Film). Effects of this solution are increased storage and work-in-progress (WIP) levels which is undesirable. Many of the interviewed facility managers admitted that their company had high levels of storage, which also is seen in the rapid plant assessment sheet, see Table 8 in section 4.4.7.

In the cross case analysis, some remanufacturing steps were in general identified as bottlenecks and/or attracted much costs. The identified steps were:

- inspection,
- cleaning and,
- reprocessing.

According to Seitz and Peattie (2004) it is practically impossible for remanufacturers to reach the lean and mass production systems as ordinary manufacturer have (see 3.2.4). This research, however, points out areas within remanufacturers that have high score in the RPAs as well as areas, which have low score. In general, the rapid plant assessments showed that the remanufacturing companies were performing well at the following measures:

- Customer Satisfaction
- People Teamwork, Skill Level and Motivation
- Ability to Manage Complexity and Variability
- Quality System Deployment

As the RPA showed and what was confirmed in the interviews, staff at the remanufacturing facilities has high motivation and dedication to quality. The author has seen that working at a company with good environmental performance is a good motivation factor for the personnel. Flexibility in the process has also been an important factor since often many types of products often are remanufactured. This is in many cases solved by the companies through workers operating in the process. Other measures in the rapid plant assessment that the companies in the case study did not perform well at were:

- Visual Management Deployment
- Product Flow, Space Use and Material Movements
- Inventory and WIP levels

The use space in the facilities is often not used efficiently. Sometimes the material is moved unnecessary far in the facility. Furthermore, space is often used as inventories between the remanufacturing process steps. The high levels of inventory in many cases occur when products await new spare parts or cores to enter the facility or when customers have yet to be found. Inventories are also sometimes used, as mentioned before, to buffer the variations in number of incoming cores. To overcome these problems, the remanufacturers need to achieve a better control over the product's design and use phase, i.e. the life cycle phases that precede the remanufacturing process. This could be achieved by adopting design for remanufacturing and/or through functional sales. Having control over the forward supply chain and the supply loops are crucial for the outcome of the remanufacturing process. This control is best performed by the original equipment manufacturers (OEMs).

The case studies further showed that the performance measures in Table 8 were similarly structured for the companies in the same type of business. This goes hand in hand with the theory that remanufacturing problems are very product type dependant. For example, the toner cartridge remanufacturers, 24 Hour Toner Services and MKG Clearprint, had low RPA score for '*management of complexity and variability*' and high RPA score for '*scheduling system*' in comparison the other studied companies. These similarities of remanufacturers operating in the same area need further investigation for verification since the RPA was conducted at only five companies.

Most of the remanufacturers operating today are independent from the original equipment manufacturer. This dissertation has pointed out many benefits for OEMs to start remanufacture. A reason to why still the independent remanufacturers are dominating, in numbers, is that they have lower overhead costs for the business.

To conclude, the remanufacturing facilities in this study can be more efficient from a lean production perspective by lowering the high levels of inventories and work in progress. Furthermore, the material movements, product flow, and use of space could be organised in a more efficient manner.

5. **How can design for remanufacturing aspects be integrated into manufacturing companies' environmental management systems?**

As described earlier, to make the investigation addressing the fifth research question more manageable, DfRem is seen as a part of DfE. One reason for this is that the remanufacturing business still is rather unknown among Swedish manufacturers (see e.g. Mårtén, 2004) and DfE is better known concept.

Important factors affecting the outcome of product oriented environmental management systems (POEMS) can be identified on four levels, in accordance with Figure 26. In short, legislation, incentives (e.g. stakeholder interests), resources, competence, availability of supportive tools and the amount of available information can be mentioned (see e.g. de Bakker, 2001). It should be stressed that companies need sufficient drivers to engage with POEMS and the outcome greatly depends on to what extent environmental problems and challenges can be transformed into business opportunities. If the manufacturer begins to remanufacture its products, it would give more incentives and understanding about how to integrate the remanufacturing aspects into the company's EMS.

The relation between DfE and EMS was shown to be weak in Swedish manufacturing industry (according to the external auditor interviews). Products are seldom brought up as significant environmental aspects although they stand for large parts of the manufacturers material flows. Much focus is still put on the manufacturing process and the scope often stays around the manufacturing facility. A reason that manufacturers do not set products as significant environmental aspects is due to the fact that it is hard for them to control what happens to them after leaving the manufacturing facility. It is then much easier to focus on the facility and its emissions. Another reason is that few external auditors require that the companies holding an ISO14001 certificate must bring up products as significant environmental aspects.

As shown in Figure 27, the requirements that the external auditors put on the manufacturers differ significantly between the auditors/certification bodies. It seems that some companies are happy to fulfil the requirements put on them in order to keep their certificate without conducting any more environmental efforts. It has been shown in research that having a standardised EMS give good opportunities to improve companies' environmental performance although the real environmental impacts may not be improved (Ammenberg, 2003).

It appears to be likely that the environmental burden from products' life cycles would be reduced if the product connection were strengthened in existing standardised EMS, which consequently would increase the environmental efficiency of EMS. Accordingly, efforts to adjust the standard ISO 14001 and the systems for its application would be advantageous from an environmental point of view.

Furthermore, the knowledge about DfE and product development among the EMS practitioners is important when integrating DfE in EMSs. When interviewing the external auditors it was observed that there is a lack of knowledge among the company EMS practitioners. The external auditors role is audit according to the EMS standard and not to work a consultant for the manufacturing companies. In some cases the auditors transfer knowledge about DfE to the manufacturers and therefore have an important role of facilitating the DfE and EMS integration.

In order to have design for remanufacturing aspects included in the manufacturing companies environmental management, these aspects should be brought up at the companies as significant environmental aspects. By doing this, there would be programs dealing with these remanufacturing aspects. Furthermore, the concept of remanufacturing should be better known among the companies and the external auditors in order to spread knowledge and put up goal for remanufacturing. If the external auditors address the manufacturers to have a life-cycle perspective on their business the manufacturer would be more likely to adapt the remanufacturing aspects in their environmental management systems.

5.3 Critical review

In this dissertation, five research questions were set in order to address the research objective. As is normal in this kind of research the amount of time and resources is limited. Since the number of remanufacturing companies with industrial process is low, especially in Sweden, the author had to gather data from overseas studies. Therefore, the studies have not been conducted in depth but this has not been seen as to affect the research results. This is due, since the research have been on a high and not detailed level concerning remanufacturers opinions of driving forces, costs, bottlenecks in the process etc. Hence, the main characteristics of the remanufacturing facilities have been identified. Furthermore, the conducted RPAs have complemented the overall picture of the analysed remanufacturing facilities. The research has, moreover, also concerned more in depth studies at the remanufacturing facility operated by Electrolux AB in Motala, Sweden. The Electrolux studies have in many ways worked as a base for the latter parts of the research.

The environmental aspects of remanufacturing have been elucidated in comparison with those generated by new manufacturing and material recycling. It was found that it is not possible to decide whether remanufacturing is environmentally preferable or not since it dependent on which of the environmental aspects that are considered to be most important. From a material resource perspective, remanufacturing was found to be preferable in comparison to new manufacturing for at least three different kinds of products. This is in line with the results of other research results earlier mentioned.

Furthermore, in this dissertation the steps that are to be included in a generic remanufacturing process have been identified. For each of these steps, the preferable product properties have also been identified in shape of the RemPro matrix. These results were verified by the case study analysis conducted in Japan, Canada and Sweden. The case study also resulted in suggestions of how to improve the efficiency of the manufacturing processes.

Finally, this dissertation included an exploration of how design for remanufacturing aspects could be better integrated into the environmental management systems at manufacturing companies.

For the first three years of the author's research much focus was put on the Electrolux facility (Sundin, 2002). The research results derived during those years have then been modified and verified through studies of other researchers' results and through the overseas case study analyses. As the previous section discussed and concluded the results of addressing the research questions the research objective is fulfilled. This dissertation has described how products can be designed to facilitate the remanufacturing process as well as described how the exiting remanufacturing processes can be improved to be more efficient.

5.4 Future research

The research within the remanufacturing area is not completed by this dissertation. There are many topics within remanufacturing that need further research. Some of the topics that have been found after conducting this research are:

- More economic studies of when and where it is beneficial for a company to start a business of remanufacturing.
- More in depth studies at remanufacturing companies to achieve a more detailed picture of the specific company situation.
- More analyses concerning how large the potential is for the remanufacturing sector has in industry.
- More research about how to link functional sale and remanufacturing businesses.
- More research concerning how products could be adapted for the combination of the concepts; functional sales and remanufacturing.

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7 Appendix

A. Remanufacturing Case Study Reports

In this appendix the summaries of the remanufacturing case studies are described.
The Case studies are presented in following order:

- 24 Hour Toner Services
- MKG Clearprint
- Cummins OER
- FUJI Film
- Scania CV AB
- Electrolux AB

The case study reports are structured in the same manner in order to enhance their readability. Most often, they start with a picture outside the facility being studied and some company facts. Furthermore, the accessible methods for collecting data are explained. Secondly, a brief history of the company is described. As a third step, the actual remanufacturing process is described and illustrated with its product mix and the facility layout. The different remanufacturing steps are explained. After this, the process flexibility, degree of automation, product logistics, and communication within the value chain are described. In the latter parts of the report, product and process adaptations are described together with the obstacles and bottlenecks in the process. Lastly, a table of the cycle times for each remanufacturing step is shown. Following the process description, the rapid plant assessments are described, including the questionnaire and rating sheet. Finally the specific remanufacturing facility analysis is shown.

In Appendix C the Interview Questions for the facility manager is presented.

Case Study at 24 Hr Toner

Company facts

Name: 24 Hour Toner
Location: 127 Sunrise Avenue, Unit 4, M4A1A9, Toronto, Canada.
Date for case study: 2003-08-14 -- 09-10
Data collection methods:

- Interview with facility manager
- Interview with team leader
- Rapid Plant Assessment
- Observations
- Secondary data from a M.Sc. thesis

Type of business: Toner Cartridge Remanufacturer

History

In 1993, Kevin O'Neill founded the 24 Hour Toner businesses with four employees. At the time, there was a large window of opportunity with high profit margins and few competitors. Initially, the company sold toner cartridges to consumers. Two years later, the company began to remanufacture cartridges as a way of insuring quality and increasing profit margins. Today, the company has seventeen employees, and its competition has increased.

24 Hour Toner is not a part of a bigger company group, but rather a small, family-run business with one remanufacturing facility and with two warehouse depots in Petersborough and Georgetown, respectively. The most important driving force for starting the business was, naturally, to gain a profit. A secondary driving force was to contribute towards stemming the flow of garbage going to landfills.

Organization and personnel

The company does not currently have an ISO9001 or ISO14001 certifications, since the management did not see the value of having these since there was no customer demand for them.

At 24 Hr Toner, five people work in the remanufacturing process, two deliver cartridges and contact repairs, two perform accounting work, and six-seven work with sales, in addition to the facility manager and owner. In the remanufacturing process, one of the workers is a team leader, and the other four are flexible workers who know how to handle all steps in the process. The workers were mostly inexperienced from the start, but were taught at the facility how to handle all the different steps. Any worker working in the remanufacturing process can perform all of the remanufacturing steps and may make the decision to discard a cartridge. Conceivably, the technician who disassembled and cleaned the core in the morning could assemble and test it in the afternoon (Williams, 2000). Furthermore, it is easy to hire people to work at the facility since pays well and the job market is tough.

Remanufacturing process

At the facility, toner cartridges are remanufactured, mostly from laser printers, photocopiers and fax machines. Only the cartridges and some other parts for printers are remanufactured. Currently, the volume of remanufactured cartridges is 1300 a month, but the goal is to reach 2000. The product mix is as follows:

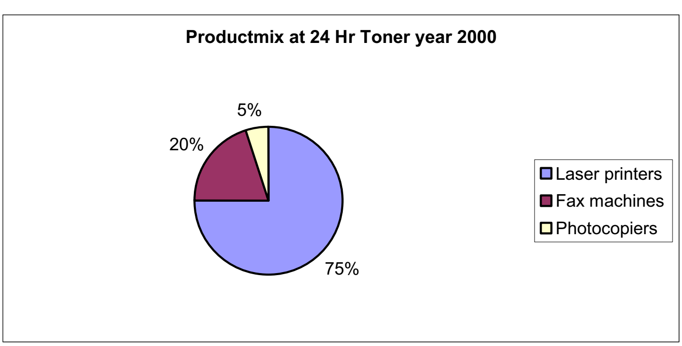


Figure 1. The product mix at 24 Hour Toner Services.

The remanufacturing process at 24 Hour Toner Services starts when the empty cartridges are received. When they arrive at the facility, they are first disassembled and then cleaned. The parts are then separated. Some of the parts are then sent to scrap dealers, while others are used for reassembly into new products. From a remanufacturing perspective, it does not really matter how many times the toner cartridge has been used, but rather the condition of the parts inside the cartridge. All parts are marked, and most of them are also replaced. Only the OEM empties have parts that are reused and they are easily identified. The cartridges are commonly reused four times, after which they are sent to material recycling. The toner is refilled using racks. On average, 11 cartridges fit in a rack, but with the larger cartridges, only 6 fit in a rack. These racks are only used in the refilling stage, as this is the most time consuming part of the process. Filling these cartridges in advance also greatly speeds up production. Following this, the parts are reassembled and tested before being shipped out. Figure 2 below depicts the flow in the facility as described above:

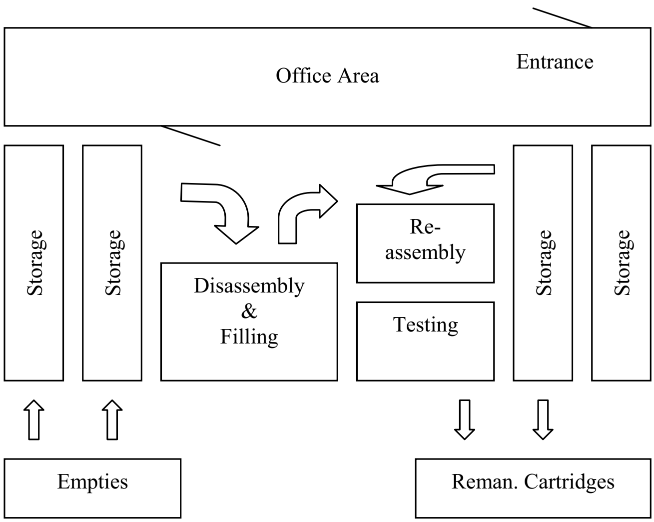


Figure 2. Process layout at 24 Hour Toner Services.

The remanufacturing of cartridges has following step sequence:

1. Receive empty cartridges from customer
2. Disassemble
3. Clean
4. Separate parts
5. Toner refill
6. Reassemble
7. Test
8. Package

The process is mostly manual, and few machines are used. The cartridges are put into racks and moved in them as well; no conveyor belts are used. The products are always taken apart, so it is seldom that the same parts end up in the same product again. The toner and the drum are always changed.

Automatization
According to the facility manager, *"if you are to automate the disassembly you are going to throw away lots of parts, which could be re-used"*. This is due to many parts that will be obsolete according an analyzing machine which can be used several times more. Since the volumes are low manual work suits the facility fine. There are plans to buy a filling machine, which would improve the filling step by making it easier and quicker.

Flexibility
The organization and process are flexible to change. The facility manager decides which products should be remanufactured and informs the team leader on a weekly basis. New products are easily integrated in the process in just a few weeks. Since the personnel have knowledge of how to remanufacture all the cartridges and do all steps in the process they are flexible.

Product logistics
The company has its own employees performing the cartridge deliveries as well as the pick-up of empties. Companies like FedEx are not used, although the company does have an agreement with UTR (Universal Toner Recovery), which trades empties with 24 Hour Toner. The company sells its remanufactured cartridges to the public and receives empties from its clients in addition to purchasing from suppliers (Williams, 2000). The empties arrive daily, but the company has no knowledge of time or the number of cartridges. Clients in the market area call in to 24 Hour Toner wanting to dispose of their empties, also on a daily basis. As the business works today, the pick-up area is rather local, although the company strives to increase its area for pick-ups. The company has federal and governmental customers, and is trying to sell to municipals too.

Legislation
There is currently no legislation of producer responsibilities or take-back laws affecting the manufacturers or the remanufacturing company.
Warranties
The remanufactured cartridges come with a 100 percent warranty from the company. The cartridges cannot affect the printers in such a way that would cause damage; therefore, the product warranties are not affected when the cartridges are remanufactured.

Contact with University
Previously, there has been a researcher from University of Toronto analyzing the garbage content at the facility. Other than that, there has been minimal contact with universities.

Communication throughout the value chain

Manufacturers
The company receives manuals from the manufacturers describing how to remanufacture the cartridges. These are seldom studied, however, since the operators find their own ways to

disassemble. Experiences from the remanufacturing are seldom shared with the manufacturers, although remanufacturing problems are occasionally faxed to the manufacturers in order to find a solution.

Customers
24 Hour Toner has a flyer that provides a detailed picture and description of parts replaced and the workings of a toner. These seem to be of little interest to the customer, however, who care primarily about price and whether the cartridge works or not.

Adaptations

The products are quite easy to remanufacture. Some of the manufacturers use special screws; otherwise, they are easy to disassembly. Some older products had difficult designs, but due to increased costs they are no longer on the market (see the following discussion concerning obstacles and bottlenecks in the process).

The process could be better adapted for remanufacturing. If the volume rises to the goal of 2 000 per month, the process could be more streamlined. As it is today, the company is working under capacity. This makes product quality a more important issue than production volumes.

Obstacles and bottlenecks in the process

According to the facility manager, it is the cleaning step that takes most of the time in the remanufacturing process, as there are many things that need to be cleaned in the cartridges. The filling process is also time consuming, and appears to be the step where efficiency could be improved the most. This could be realized by investing in a filling machine. Furthermore, testing is taking long time and is seen as the bottleneck of the process. Currently, one operator tests all the cartridges.

As far as costs, the most costly step is reassembly since many new spare parts replace old parts. This cost is more closely linked to purchase than the actual remanufacturing step. Space is also an issue at the facility, as the business has grown and more space is needed.

Another obstacle in the process is caused by the toner cartridge design. Some manufacturers integrate computer chips in the cartridges, which need to be reprogrammed in order to have the remanufactured cartridge function properly. This adds time to the remanufacturing process. According to the facility manager, these chips do not necessarily improve the cartridges, and they only affect the customers in a negative way in the form of higher prices.

Working environment
The working environment around the remanufacturing process is pleasant, with low sound level and clean work areas. The facility does not have any big machines running, and the remanufacturing volumes are relatively low.

Production figures
There are no exact times when the empties are picked up or the remanufactured cartridges are delivered. Different customers use their cartridges for different length of time, i.e. some take a few days while others a few months to use the cartridges.

There is no special batch size used for the deliveries, since it is up to the customer to decide in what quantities they are to be delivered. The company receives approximately 15-20 orders a day.

Table 1. Operation times.

Remanufacturing Step	**Operation Time (min)**	**Operation Time (%)**
Disassembly	15 min	25 %
Cleaning	15 min	25 %
Toner Refilling	6 min	10 %
Reassembly	18 min	30 %
Testing	6 min	10 %
Total	**1 hour**	**100 %**

The figures in Table 1 represent the operation times for the remanufacturing steps. At 24 Hour Toner, the operators do not necessarily conduct all remanufacturing steps for a set of cartridges each day. This means that a set of cartridges may go through 2-3 steps one day, and the remaining steps the next day. There are no shift-times, and the cartridges jump, from one step to another.

There are five operators in the remanufacturing process conducting all steps for 138 different product types. The operators work 8-hour shifts with a 40 minute break for lunch and two 15 minute rest breaks. There is also an opportunity to work on Saturday if the company is busy and there is a supervisor available.

As seen in Figure 1, much of the facility area consists of storage space. The storage for incoming empties includes upwards of 3000 empties. These are categorized into two categories; virgins and non-virgins, where the virgins have only been used ones. The company has a policy of not buying non-virgin cartridges from the suppliers e.g. UKP. Other cartridges that are retrieved from clients are not distinguished as virgins or non-virgins. Furthermore, customers are told that a recycling fee is included in the price when bought.

There is no exact record of how many spare parts stored are in the facility maybe thousands although the company maintains records on how many new spare parts that are ordered to the facility. There were no available figures on how long it takes before a spare part is used, though all the new spare parts are used and do not end up on the shelf. What parts that are on the shelves depends on what leaves the facility, which is unknown by the company.

Rapid Plant Assessment

According to the questionnaire of 20 questions in the RPA-sheet in Figure 3, the number of yeses was 8 out of 20. Synthesizing these in the rating sheet, Figure 4, a leanness number of 55 was achieved. In the sheet, one can conclude that the company should improve the material flows in the process and the use of space. Other parts that need to be considered are the amounts of inventory and work-in-progress. Improving the integrating of the supply chain can change much of these things.

Plant	Rapid Plant Assessment Date 2003-08-14	
No	Table 2--Assessment Questionnaire	Yes/No
1	Are visitors welcomed and given information about plant layout, workforce, customers, and products?	Y
2	Are ratings for customer satisfaction and product quality displayed?	N
3	Is the facility safe, clean, orderly, and well lit? Is the air quality good and noise levels low?	Y
4	Does a visual labeling system identify and locate inventory, tools, processes, and flow?	Y
5	Does everything have its own place, and is everything stored in its place?	N
6	Are up-to-date operational goals and performance measures for those goals prominently posted?	N
7	Are production materials brought to and stored at line side rather than in separate inventory storage areas?	N
8	Are work instructions and product quality specifications visible at all work areas?	N
9	Are updated charts on productivity, quality, safety, and problem solving visible for all teams?	N
10	Can the current state of the operation be viewed from a central control room, on a status board, or on a CRT?	N
11	Are production lines scheduled off a single pacing process with appropriate inventory levels at each stage?	Y
12	Is material moved only once as short a distance as possible and in appropriate containers?	N
13	Is the plant laid out in continuous product flow lines rather than in "shops"?	N
14	Are work teams trained, empowered, and involved in problem solving and ongoing improvements?	Y
15	Do employees appear committed to continuous improvement?	Y
16	Is a timetable posted for equipment preventive maintenance and continuous improvement of tools and processes?	N
17	Is there an effective project management process, with cost and timing goals, for new product start-ups?	N
18	Is a supplier certification process--with measures for quality, delivery, and cost performance--displayed?	N
19	Have key product characteristics been identified and fail-safe methods used to forestall propagation of defects?	Y
20	Would you buy the products this operation produces?	Y
	Total number of Yeses	8

Figure 3. RPA assessment questionnaire for 24 Hour Toner Services.

Rated by: Erik Sundin
Tour Date: 2003-08-14

Rapid Plant Assessment
Table 1--Rating Sheet **Plant:** 24 Hr Toner

No	Measure	Poor	Below Average	Average	Above Average	Excellent	Best in Class	Scores
	Ratings → / **Score →**	1	3	5	7	9	11	
1	Customer Satisfaction					x		9
2	Safety, environment, cleanliness, & order				x			7
3	Visual Management Deployment		x					3
4	Scheduling system				x			7
5	Product flow, space use & material movement means	x						1
6	Inventory & WIP Levels			x				5
7	People teamwork, skill level, & motivation			x				5
8	Equipment & tooling state & maintenance			x				5
9	Ability to Manage Complexity & Variability		x					3
10	Supply Chain Integration		x					3
11	Quality System Deployment				x			7
	Totals →	1	9	15	21	9	0	55

Figure 4. RPA rating sheet for 24 Hour Toner Services.

Company analysis

The company has large storage areas, which are more costly and need to be reduced. Better knowledge about which and how many cartridges that are incoming could improve the process since the storage of spare parts could be adapted for incoming cartridges instead of having many spare parts for many types of cartridges. The current storage arrangements require too much space, considering both storage for the empties and storage for new spare parts. Furthermore, all parts that are put in storage holds capital for the company, which could be used more wisely.

A problem with this type of operation is that the original manufacturer operates in the same market having the same customers, with the competition affecting the design of the cartridges negatively. Hence, the products are not designed for remanufacturing. If the OEMs had their own remanufacturing business, the cartridges would most likely have been adapted for remanufacturing. Now, when independent remanufacturers remanufacture cartridges to the same market, the cartridges are optimized for new manufacturing. Due to this, the customer ends up paying more for the remanufactured cartridge than actually is needed.

Since volumes are rather low (16 000 cartridges per year) and number of products is high (160), it is of the utmost importance to have a flexible process. This is through the use of manual operators, who can perform every step in the remanufacturing process. Communication from the process leader and the operators works smoothly.

The pick-up of empty cartridges are managed by phone, and it is not known how many and which kinds of cartridges that arrive to the facility. These could be conducted more efficient by having the pick-up information managed through the Internet. The pick-up operators also could use PDAs in order to keep them updated on where to pick-up new empties as the day goes by.

Cleaning and toner refill are the steps that allocate the longest time in the process. The company could prepare to buy a filling machine as suggested to improve at least the filling step. A second testing machine should be installed in order to speed up the process.

Since the company is working below capacity, it could focus on making the process more efficient by reducing the length of walking distance between the remanufacturing steps or even by introducing some sort of conveyor belt where the cartridges could be transported on. As the process is designed today, the operators must walk around the facility for the different steps.

Case Study at MKG Clearprint

Company facts

Name: MKG Clearprint
Location: 1090 Lorimar Drive, Mississauga, ON L5S 1R8, Canada.
Date for case study: 2003-09-14 -- 09-30
Data collection methods:

- Interview with facility manager.
- Interview with team leader.
- Rapid Plant Assessment
- Secondary data from brochures.
- Observations.

Type of business: Toner Cartridge Remanufacturer.

History

MKG Clearprint started its business in 1989. Since then the company has become a world leader in the remanufacturing of high-quality laser toner cartridges. The incentive to start the business was to make money. Environmental concerns are included in the company and although they do not use ISO14001. The company is aware that its business is good for the environment, which is used as a marketing point in customer brochures.

MKG Clearprint is not a part of a bigger company group, and the facility in Mississauga is the only one of its kind. In good times, there are 400 people working in the company. MKG Clearprint has an ISO9002 certificate, issued in 1996, which helps management to structure the quality management system at the facility.

Remanufacturing process

At the facility, toner cartridges from laser printers are remanufactured. Currently, the volume of remanufactured cartridges is 240,000 annually. The product mix is as follows:

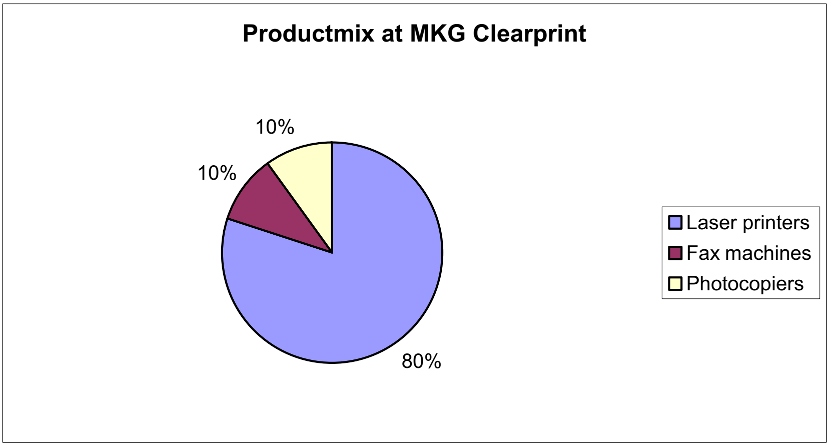
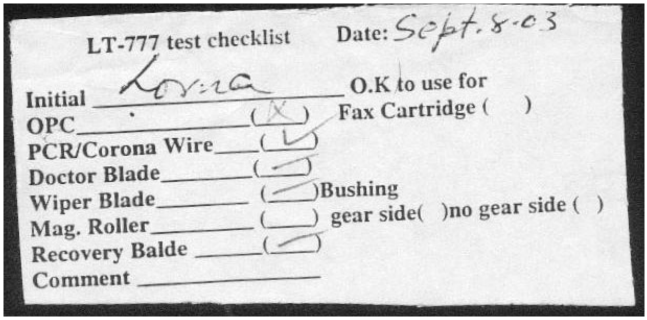


Figure 1: Product mix at MKG Clearprint.

In the first step all the empties are sorted and stored according to product type and a differentiation of virgin or non-virgin is made. In the next steep, the cartridges are tested with a testing machine (LT-777), which indicates which of the cartridge parts that are reusable. An example of such a note is shown in Figure 2.



LT-777 test checklist Date: Sept. 8-03

Initial Lorna O.K to use for
OPC____________(X) Fax Cartridge ( )
PCR/Corona Wire____(✓)
Doctor Blade________(✓)
Wiper Blade________(✓)Bushing
Mag. Roller________(__) gear side( )no gear side ( )
Recovery Balde ______(✓)
Comment ____________

Figure 2: LT-777 test checklist.

In the disassembly process the reusable parts are separated for further processing while the non-reusable parts are recycled. The different parts in the cartridge witch are manually verified are; the waste hopper, the developer unit and the drum with its included parts. The parts that are recycled are replaced with newly manufactured parts and these are; toner, drums and seals. Next, the cartridges are assembled at the same place in the line as they were disassembled. Then the cartridges are tested to ensure that it has the right quality, and are then tagged, labeled and packed in sealed bags for shipping. Different customers have different requirements on how the cartridges should be labeled. The tagging is used for tracability reasons according to the ISO9002 standard.

All metal parts that are not remanufactured are recycled, e.g. wiper blades, doctor blades, magnetic roller sleeves, primary charge rollers and drums. Plastic parts such as waste hopper and developer are scrapped if broken. These only represent 5-10 % of all the cartridges processed.
The remanufacturing of cartridges has the following step sequence (as described above):

1. Receive and sort the empty cartridges
2. Analyse the cartridges
3. Disassemble the cartridges
4. Reassemble the cartridges and refill toner
5. Post test
6. Tagging and bagging the cartridges
7. Package the cartridges

Figure 3 shows the work flows in the facility.

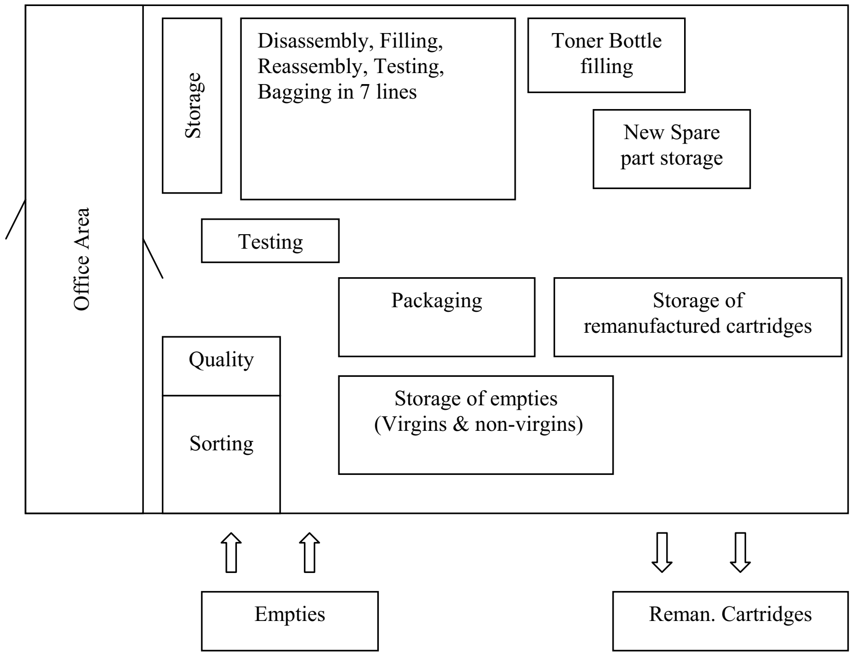


Figure 3: Process layout at MKG Clearprint.

The process is station based although the stations are laid out in logical flow sequence. Some conveyor belts are used, but mostly the cartridges are moved between the stations by means of carts.

Organization and personnel

Every disassembly/reassembly line has 10-16 operators including a 'lead hand', who functions as team leader. Five people work with a lead hand at the sorting station. The packaging station holds eight people, including lead-hand. Three people at the analyzing station, as well as at the refilling station. There are 8-10 floaters and shippers. In the spare part storage two people are working.

The lead hand is in charge of a specific line. He/she is in charge of providing material for the operators, preparing information and sometimes helping out. Making sure that the operators follow the procedures they are in charge of.

Automation

There are a few stations that have automation; foam packaging, toner filling and the skid wrapping.

Flexibility
The facility manager claims that the company has good flexibility to switch between different types of cartridges. It takes about 30 minutes to switch to a new product type and 80 percent of the process is flexible for all kinds of cartridges. The operators are also quite flexible; workers in the disassembly and reassembly steps have knowledge of different kinds of cartridges, which are all marked and overviewed, in a manager matrix. One of the lines is designed for special cartridges, which are remanufactured at low volumes. In that line especially the workers have to have good skills and work with high flexibility.

Product logistics
MKG Clearprint has contracted some courier companies to deliver empty cartridges and deliver the finished products on a daily basis.

Legislation
There is some applicable legislation, as mentioned in the Environmental Protection Act EPA (-9(1)(a)).

Warranties
The customer has a special complaint number to call should they encounter a problem with their cartridge. There is a special group at the facility that deals with these issues. Once a quality problem occurs the errand gets a number (RGA). Warranties are due for a year, which is as long as the manufacturer also gives.

Contact with University
There has not been that many co-operations with universities although there was a Master student studying the product design of the cartridges.

Communication throughout the value chain

Manufacturers
The original equipment manufacturers are not happy about MKG's remanufacturing and therefore less communication occurs. Xerox comes to watch the process but they are again one of MKG´s customers.

Customers
The customers receive various specifications such as yield and refractive density if it is necessary and required.

Adaptations
The experience at MKG is that the OEMs are trying to make the cartridges more complicated to remanufacture. By putting chips in them, for example, MKG is forced to re-engineer the chip. The OEM tries to make it complicated for the remanufacturers. Sometimes the OEMs are putting the pieces together very hard, mold it, melt it, before they used clips – making it more time, we need to spend more time that we are assigning. Making it more time consuming, which makes the MKG remanufacturing less competable with higher prices. In general, when customers see that the price is not so much different they prefer to go to the OEMs. At MKG, the yields are better

than at the OEMs though their customer prices are on average 50-60% lower. The quality is comparable with the OEMs and the customers are happy with the combination and price and quality offered to them by MKG. According to MKG, there is room for improvement in the process. For example, making the working areas more flexible and nice for the operators. Making the handling of parts easier. One thing that has been discussed is to have one disassembly station followed by an assembly station.

Obstacles and bottlenecks in the process

In general, the disassembly takes longest time in the process followed by the assembly, according to the facility manager. Sometimes, for some products, the reassembly takes longer time than the disassembly. The step that allocates the highest share of cost is the toner filling station, according to MKG since toner is the critical raw material for the cartridges.

The manager of MKG thinks that the disassembly/reassembly step has most potential for improvement. The company is considering investment in new tools and/or machines. As the market looks like today, no investments are to be seen in the nearest future. The remanufacturing process is rather labor intensive, which, according to the facility manager, makes the obstacles vary in line with the mood of the operators. Hence, if the operators feel good, they will work more efficiently. An effort to solve these obstacles could be to improve the operators working environment.

Furthermore, the bottleneck in the process is assumed by the facility manager to be the analyzing step. There are 7 lines for disassembly, and reassembly and MKG only has 3 analyzing machines to provide the lines with analyzed cartridges. When this bottleneck occurs, some of the operators from the disassembly/reassembly lines have to go by experience on how to disassembly the cartridges and choosing which components to replace. The operator then gets feedback of his/hers decision when post-testing the cartridge.

Working environment

The impression of the visit at MKG the cleanliness of the facility seemed fairly nice al though the sound level at some points was quite high.

Table 1: Operation times.

Remanufacturing step	Operation time (min)	Operation time (%)
Sorting	1 min	6
Testing	1 min	6
Refilling	1 min	6
Disassembly	5 min	30.5
Reassembly	5 min	30.5
Post-testing	1 min	6
Bagging	0,5 min	3
Packaging	2 min	12
Total	**16.50 min**	**100 %**

Rapid Plant Assessment

The question filled in the rapid plant assessment in Figure 3 show 11 yeses and in the connected matrix (score: 65) it is only the part that deals with material flows, space use, material movement means that are below average. This implies that MKG should work with these issues and improve its remanufacturing process. Of course, there are other issues to consider, but previoulsly mentioned things are most important to deal with.

Rapid Plant Assessment Date 2003-09-09	
Table 2--Assessment Questionnaire	Yes/No
Are visitors welcomed and given information about plant layout, workforce, customers, and products?	Yes
Are ratings for customer satisfaction and product quality displayed?	Yes
Is the facility safe, clean, orderly, and well lit? Is the air quality good and noise levels low?	Yes
Does a visual labeling system identify and locate inventory, tools, processes, and flow?	Yes
Does everything have its own place, and is everything stored in its place?	
Are up-to-date operational goals and performance measures for those goals prominently posted?	
Are production materials brought to and stored at line side rather than in separate inventory storage areas?	No
Are work instructions and product quality specifications visible at all work areas?	Yes
Are updated charts on productivity, quality, safety, and problem solving visible for all teams?	Yes
Can the current state of the operation be viewed from a central control room, on a status board, or on a CRT?	No
Are production lines scheduled off a single pacing process with appropriate inventory levels at each stage?	Yes
Is material moved only once as short a distance as possible and in appropriate containers?	No
Is the plant laid out in continuous product flow lines rather than in "shops"?	No
Are work teams trained, empowered, and involved in problem solving and ongoing improvements?	Yes
Do employees appear committed to continuous improvement?	
Is a timetable posted for equipment preventive maintenance and continuous improvement of tools and processes?	No
Is there an effective project management process, with cost and timing goals, for new product start-ups?	No
Is a supplier certification process--with measures for quality, delivery, and cost performance--displayed?	Yes
Have key product characteristics been identified and fail-safe methods used to forestall propagation of defects?	Yes
Would you buy the products this operation produces?	Yes
Total number of Yeses	11

Figure 3: RPA questionnaire

Rated by:	Erik Sundin	Rapid Plant Assessment						
Tour Date:	2003-09-09	Table 1--Rating Sheet				Plant:	MKG Clearprint	
	Ratings →	Poor	Below Average	Average	Above Average	Excellent	Best in Class	
No	Measure ↓ / Score →	1	3	5	7	9	11	Scores
1	Customer Satisfaction					x		9
2	Safety, environment, cleanliness, & order			x				5
3	Visual Management Deployment			x				5
4	Scheduling system				x			7
5	Product flow, space use & material movement means		x					3
6	Inventory & WIP Levels			x				5
7	People teamwork, skill level, & motivation				x			7
8	Equipment & tooling state & maintenance			x				5
9	Ability to Manage Complexity & Variability			x				5
10	Supply Chain Integration				x			7
11	Quality System Deployment				x			7
	Totals →	0	3	25	28	9	0	65

Figure 4: RPA Worksheet

Analysis

MKG Clearprint has quite high product volumes (240 000 annually), which gives it good possibilities for using lines in its remanufacturing process. As the process looks today, it is although rather station based operation. The remanufacturing steps could be situated more closely together to avoid unnecessarily long transports. Furthermore, the steps of disassembly, reassembly and testing could be more streamlined with parallel flows for different kinds of products. This change would most probably increase the efficiency of the remanufacturing process. The operators need to go several times to the bench for disassembly/reassembly and the testing area before having the cartridge delivered to the following step.

Some parts are automated, which speeds up the workflow. Since there is only one machine performing the analyzing before disassembly, MKG should consider investing in a second testing machine. The rest of the process is primarily manual which makes the process highly flexible for the various kinds of products being remanufactured.

If the disassembly / reassembly steps are redesigned MKG should also consider to make the working conditions better in the facility e.g. lowering the level of noise and let the operators shift positions in their lines. Putting the remanufacturing steps closer to each other while reducing the number of cartridges in storage would most likely make the process more efficient and lean.

Case Study at Cummins OER

Company facts

Name: Cummins OER
Location: 10 Canfield Drive, Markham, ON L3S 3J1, Canada
Date for case study: 2003-09-22 -- 10-30
Data collection methods:

- Interview with facility manager.
- Rapid Plant Assessment
- Observations
- Secondary data from two B.A.Sc. thesises

Type of business: Gasoline Engine Remanufacturer

History

Cummins OER was founded in 1957 by Volkswagen Canada to remanufacture the "Beetle" engine. In the time since its start, the company has grown to have customers such as Chrysler and Saturn. Cummins bought the operation from Volkswagen Canada in 1998. Cummins OER was originally located in Scarborough, but during 2001 the business was relocated to the Markham area.

The main goal of this business is to make money, and Cummins OER does this through remanufacturing. There are other considerations such as plant capacity of original engine manufacturing to provide capacity, hence they could utilize their equipment for new manufacturing and Cummins OER will provide the capacity through remanufacturing operation. Recycling of parts (remanufacturing) is a good thing to do from a business standpoint.

Cummins OER is a part of a company group, the 8th division of Cummins Engine Company that manufactures and remanufactures diesel engines for the automotive and non-automotive sectors. The facility that was analysed in Markham remanufactures gasoline engines for the automotive sector. Within the parent company there is a company called Diesel Recon that deals with the remanufacturing of diesel components. Cummins is a worldwide operation and it includes remanufacturing facilities in Memphis (Tennessee, USA), El Paso (Texas, USA) San Luis Potosi (Mexico), Juarez (Mexico) and Cumbernauld (Scotland). Worldwide, there are over 20000 employees in both new and remanufacturing operations. Within this facility, there are approximately 180-200 employees focusing on non-Cummins products.

Cummins OER has a number of certifications, such as; TS16949, ISO14001 and QS9000, (which has migrated to TS16949). The ISO14001 was acquired this year, while TS (and QS) has been enforced for at least 4-5 years. The ISO14001 has affected the facility production system in different ways, such as reviewing the packaging from an environmental perspective and modifying techniques and technologies to better deal with environmental questions. Furthermore, the containment of chemical spills has been reviewed, making sure that the company has the capacity to care of these accordingly. Also, Cummins OER had to review the environmental impacts of this facility in addition to the legal requirements for the Markham area.

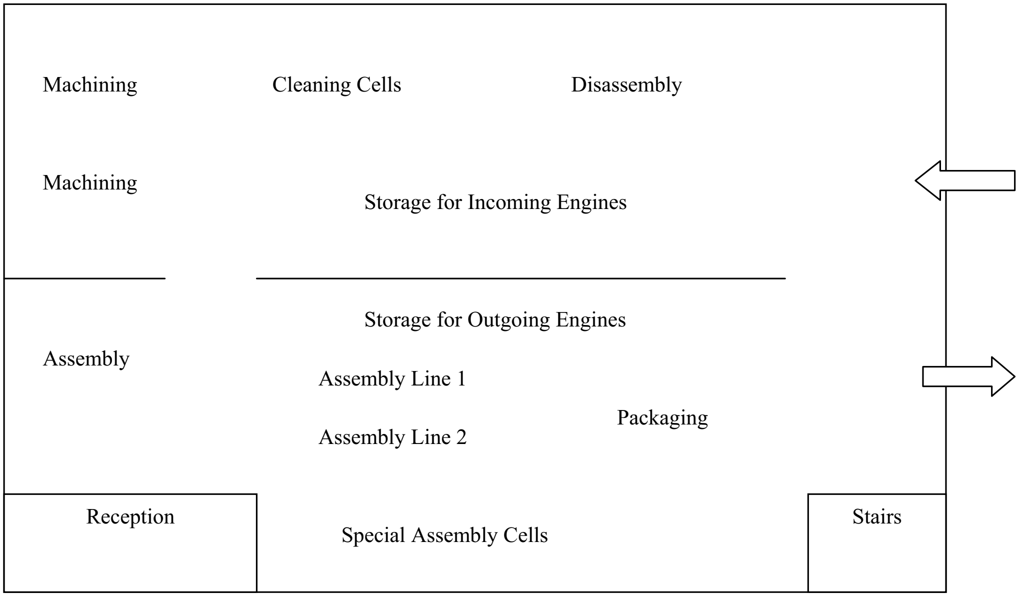
Remanufacturing process

As mentioned earlier, Cummins OER remanufactures gasoline engine from various manufacturers. The product mix is confidential as well as the remanufacturing volumes. The basic flow of remanufacturing starts with disassembly of the engine core into its various components. Following this the engine goes through a cleaning process where dirt and debris are removed. Several parts then undergo a machining process where the machine is re-qualified to its right size, and where major sealing and running surfaces are treated. The next step is the assembly process, where the engine is put back together. Following this, the engines are cold-tested for compression oil flow, and leak down tested for water cavities. The last step is packaging and storing pending shipping.

The remanufacturing process at Cummins OER include the following steps:

1. Disassembly
2. Cleaning
3. Machining process
4. Assembly
5. Cold test and other tests
6. Packaging

Ground floor: Remanufacturing area



First floor: Offices for support staff

Figure 1: Process layout at Cummins OER.

The workflow in the remanufacturing process is very station-based. There are approximately five areas in the plant that parts travel through. Depending on the need, it is not a straight flow through some of the areas; disassembly and cleaning for example is not a straight process. The other areas in the remanufacturing are fairly straight but they are station based. Some parallel flows exist in some machining areas.

Organization and personnel

At Cummins OER, there are teams of workers that are based on the type of work being done and which are grouped into what are referred to as "work shops". There are three major sections: assembly, machining and disassembly. Within each of these there are teams. Among the workers there are some specialists; however, the operators are trained in a general manner and qualified to work everywhere in the team. The workforce for the most part can accommodate absences and variations. From a work force education standpoint, Cummins OER has everything from Ph.D.s to high school graduates. A number of operators maintain automotive mechanic licenses as well as machinist licenses; electricians are licensed as well. From a staff perspective, the company has professional engineers licensed by the province of Ontario as well as engineers in the appropriate disciplines in manufacturing systems and material systems.

When a operator comes into the business, an education program is initiated followed by classroom training for the specific work group station, followed by job training followed by process training for that particular station. Besides the remanufacturing operators there are typical staff support, engineers, quality, health and safety, manufacturing engineering and production engineering employed at the company.

Automation
Very little of the routine remanufacture is automated, and the use of robotics is minimal. However there is some machining of components and automated cells using CNC.

Flexibility
Cummins OER maintains a high degree of flexibility for equipment setup, tooling and fixture design as well as assembling processes as they must sustain a high degree of flexibility variation. The process must be able to remanufacture many types of engines; in the process, for exampel 30 of one kind of product might need to be manufactured followed by something completely different. Generally, Cummins OER can put new machines in the remanufacturing process, and these would be driven by more capacity requirements than by changes in the process.

Product logistics
Products are delivered by semi-truck trailers. Although some components are air-shipped for product parts in smaller volumes, most of them are delivered by trucks and removed by trucks to the facility. The used engine cores are collected in a customer depot, which then is transported to the facility depot. Cummins OER customers dictate what type of transportation method that is used for deliveries. Generally there are trucks used in both directions and component parts are delivered in whatever the supplier method is. Trucks come in and go out every day. Some customers deliver on a weekly basis while others deliver three times a week. Each load is a mixed load of cores coming in. From a prediction standpoint, Cummins OER receives very little information concerning witch cores that are going to be on the trucks. Cummins OER knows the history of the incoming engines, but does not consider this information, important as a full inspection is always assumed to be needed.

Legislation
The facility manager is not aware of any laws concerning product take-back or producer responsibilities affecting the company.

Warranties
The customers of Cummins have their own warranty strategy toward their own end-users.

Contact with University

A few years ago, two students from the University of Toronto conducted their B.A.Sc. projects at Cummins, which looked at its work- and material flows.

Communication throughout the value chain

Manufacturers
Cummins OER has daily communication with the manufacturers concerning launching new product. The company holds for design controls and product repairs. Cummins process must meet the manufacturers expectations, witch are communicated often at the start of a product and through out the products life cycle. Communications occurs via phone calls, emails and visits. Primarily, the Cummins OER staff works with the remanufacturing and experiences are very rarely used in new designs.

Adaptations

Product
Considering product design, there is always a tradeoff between the cost of manufacturing new products and costs for remanufacturing. If the share of remanufactured products goes up in comparison with newly manufactured products, Cummins OER will have a larger impact on the overall company costs. If, on the other hand this remains low, then product design should be optimized for new manufacturing, and not remanufacturing.

Process
The company continuously applies new strategies for remanufacturing and implements various techniques into the remanufacturing process.

Obstacles and bottlenecks in the process

As far as efficiency, the facility manager suspects the cleaning step could be the most improved; this step is also the most labor intensive and most time consuming, takes a lot of space and one of the most complex areas in the business. Based on numbers it is uncertain but based on complexity and the amount of parts that go through it. The bottleneck of the process, therefore, is assumed to be the cleaning step. Component machining has the highest share of the cost. This is due to the large capital investment, number of operators, and consumable supplies. Second in cost is cleaning, based on consumable suppliers and labour costs. The assembly operations are the final area where labour is the main cost driver.

According to a manager at Cummins OER, product cleanliness is a challenge to any remanufacturing process, and Cummins OER is no exception. The machining tolerances and expectations of the customer in this area also drive improvements.

Working environment
The working environment at Cummins OER seems to be of ordinary industrial character. Nothing special was noticed during the facility tour. Some stations might have high sound levels, but there the operators wear earphones.

Lean Production figures:

Table 1: Operation times.

Remanufacturing Step	**Cycle Time in time**	**Cycle Time in percentage**
Disassembly	Confidential	Confidential
Cleaning	Confidential	Confidential
Machining	Confidential	Confidential
Reassembly	Confidential	Confidential
Cold tests	Confidential	Confidential
Packaging	Confidential	Confidential
Total	**2 weeks**	**100 %**

Rapid Plant Assessment

In the RPA, Cummins OER scored well in the categories of 'ability to manage flexibility and variability' and 'Quality System Deployment'. This might be the result of its long experience and demanding quality standards. On the other hand, the company scored poorly when it came to 'Product flow, space use & material movement means' and 'Inventory & WIP Levels'. The following are the results of the company's RPA questionnaire (Figure 2) and sheet (Figure 3).

Plant	Rapid Plant Assessment Date: 2003-09-22	
No	Table 2--Assessment Questionnaire	Yes/No
1	Are visitors welcomed and given information about plant layout, workforce, customers, and products?	No
2	Are ratings for customer satisfaction and product quality displayed?	Yes
3	Is the facility safe, clean, orderly, and well lit? Is the air quality good and noise levels low?	Yes
4	Does a visual labeling system identify and locate inventory, tools, processes, and flow?	No
5	Does everything have its own place, and is everything stored in its place?	No
6	Are up-to-date operational goals and performance measures for those goals prominently posted?	No
7	Are production materials brought to and stored at line side rather than in separate inventory storage areas?	No
8	Are work instructions and product quality specifications visible at all work areas?	Yes
9	Are updated charts on productivity, quality, safety, and problem solving visible for all teams?	No
10	Can the current state of the operation be viewed from a central control room, on a status board, or on a CRT?	No
11	Are production lines scheduled off a single pacing process with appropriate inventory levels at each stage?	No
12	Is material moved only once as short a distance as possible and in appropriate containers?	No
13	Is the plant laid out in continuous product flow lines rather than in "shops"?	No
14	Are work teams trained, empowered, and involved in problem solving and ongoing improvements?	Yes
15	Do employees appear committed to continuous improvement?	Yes
16	Is a timetable posted for equipment preventive maintenance and continuous improvement of tools and processes?	No
17	Is there an effective project management process, with cost and timing goals, for new product start-ups?	Yes
18	Is a supplier certification process--with measures for quality, delivery, and cost performance--displayed?	Yes
19	Have key product characteristics been identified and fail-safe methods used to forestall propagation of defects?	Yes
20	Would you buy the products this operation produces?	Yes
	Total number of Yeses	9

Figure 2: RPA questionnaire

Rated by: Erik Sundin
Tour Date: 2003-09-22

Rapid Plant Assessment
Table 1--Rating Sheet **Plant:** Cummins OER

No	Measure / Score	Poor 1	Below Average 3	Average 5	Above Average 7	Excellent 9	Best in Class 11	Scores
1	Customer Satisfaction				x			7
2	Safety, environment, cleanliness, & order			x				5
3	Visual Management Deployment		x					3
4	Scheduling system		x					3
5	Product flow, space use & material movement means	x						1
6	Inventory & WIP Levels	x						1
7	People teamwork, skill level, & motivation				x			7
8	Equipment & tooling state & maintenance			x				5
9	Ability to Manage Complexity & Variability					x		9
10	Supply Chain Integration				x			7
11	Quality System Deployment					x		9
	Totals	2	6	10	21	18	0	57

Figure 3: RPA Worksheet

Analysis
Cummins OER has remanufactured for a long while (56 years) and is certified with quality and environmental standards, all of which is reflected in their remanufacturing processes. For example, environmental issues regarding packaging, chemicals spills and processes are strongly regarded.

The material flows are quite good since the process steps in the facility are laid out in a logical sequence. The level of storage is little bit too high, especially since the first part of the process (disassembly-cleaning-machining) is performed separately from the second part (assembly-test-packaging). With the first part more station-based than the latter part. Furthermore, the machining process includes some parallel flows using two assembly lines, which, in turn reduces the possibilities for these steps to be bottlenecks in the process.

The company has a strong relationship with manufacturers since they are both Cummins OER suppliers and customers. The remanufacturing process at Cummins must follow the requirements of the manufacturers. The cleaning step could be improved, since it is most labour intensive and takes the longest time. Further, more component machining has a great deal of consumable supplies and capital investment, which makes it more costly. Machining and assembly are two steps that have high labour costs and which might be reduced.

Case Study FUJI Film

Company facts

Name: FUJI Film
Location: Ashihagara, Japan
Date for case study: 2003-12-03
Data collection methods:

- Interview with facility managers
- Observations
- Secondary data from brochures

Type of business: Single-use Camera Remanufacturer

History

In 1990 FUJI Film began to manufacture single-use cameras. It became a very popular product, and was subsequently mass-produced. The nature of these products is that they are often returned to the photo shop in order to have the photos developed. This nature of the single-used cameras led to the accumulation of numerous used cameras at the photo shops. During this time, there was also an increase in environmental awareness, and criticism was directed towards the single-use cameras, since their batteries were used only once. FUJI Film then realised that they needed to take responsibility for collecting and recycling their single-use cameras.

All of the four manufacturing facilities in the Ashihagara area hold ISO9001 and ISO14001 certifications. There are around 250 employees at the Ashihagara area and 50 of them work in the remanufacturing facility. The production volumes for single-use cameras were in 2004 approximately 60,000,000 annually. Out of these, 60 percent were produced in the remanufacturing facility, i.e. 36,000,000. Internationally, FUJI Film has other remanufacturing facilities: two in Greenwood, South Carolina, USA and one in Kleve, Germany. These, however, do not have the same level of automation as the Ashihagara facility. Within the FUJI company group, there is also FUJI Xerox, which remanufactures fax machines.

Remanufacturing process

In the Ashihagara remanufacturing facility, there are about 15 types of single-use cameras collected. Of these incoming cameras, 90 percent are remanufactured while the rest are being material recycled. For the remanufacturing of the main types, the process is fully automated. The cameras that are not mainstream are processed manually.

Once the products arrive at Ashihagara, they will go through the following set of procedures:

1. Sorting
2. Disassembly
3. Cleaning
4. Inspection
5. Repair
6. Assembly
7. Inspection
8. Packaging

The layout of the Ashihagara facility is displayed in Figure 1:

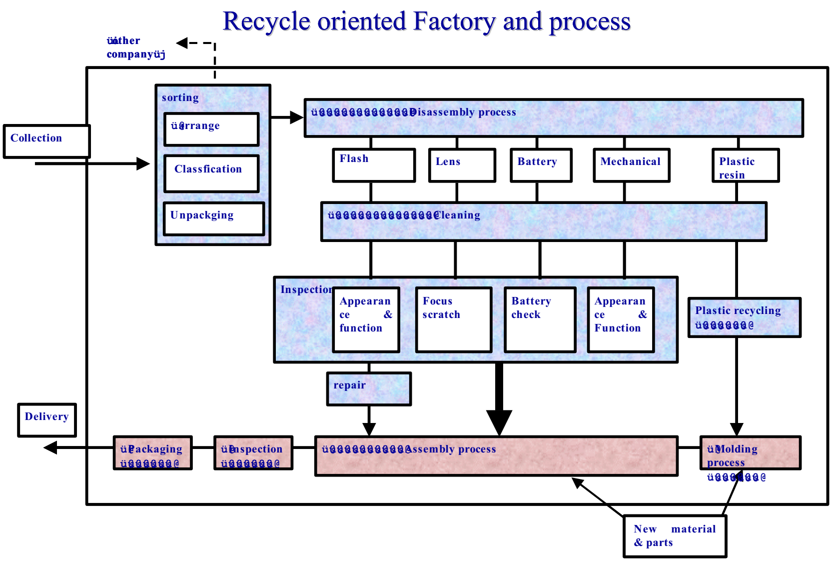


Figure 1: Process flow layout at FUJI Film, Ashihagara, Japan.

In the sorting step, the cameras that are automatically processed and the cameras that need to be remanufactured manually are separated. Following the sorting step, the automatic process is a fast, straight and singular flow. After disassembly, all components are processed in parallel. (see Figure 1).

Although the process is primarily automatic, 50 people work at the remanufacturing facility as previously mentioned. These workers have at least a high school education, and they are divided into independent work groups with leaders and operators. For maintenance and process improvements, electronic and process engineers are hired.

Flexibility

The remanufacturing line is flexible in terms of changing machines/robots. A new part of a line could be test ran aside and then put into the operating line without disturbing the production flows much. Sometimes only small changes are made, such as changing only one robot/machine.

The facility is product flexible for remanufacturing various kinds of camera designs, just as long as it sticks to the 'unit design' adapted for the remanufacturing process. This means that the single-use cameras have a certain number and position of holes where the robots can disassemble the cameras. These cannot be changed, although the rest of the camera can have various shapes.

Product logistics
The cameras are collected from the photo shops all around Japan by FUJI Color Sale. As a second step, they are transported to any of the six warehouses that FUJI Film operates in Japan. At this point other brands are sorted out and traded to their manufacturers and vice versa. Following this first sorting step, the cameras are brought to the remanufacturing facility in Ashihagara. Since volumes are high and there are six different warehouses that supply the remanufacturing facility with cameras they, can expect daily deliveries of used single-use cameras. The camera transports to the facility are collaborated with the transports of chemicals to the Ashihagara factories.

There are large variations during the year of the number of products arriving at the facility. This is due to the different holiday seasons in Japan. FUJI Film has figures, which forecast the number of cameras that will come to the facility. The changes in camera supplies even out through an intermediate buffer of cameras waiting to be remanufactured at the facility.

Each day remanufactured cameras are shipped out to intermediate warehouses upon orders from retailers. The remanufactured cameras cannot be stacked at the Ashihagara facility. Monday through Saturday the company ships out approximately 40 to 50 pallets. Each pallet contains about 5 000 cameras, which makes 250,000 cameras (i.e. around 3 trucks) going on Monday through Saturday.

Warranties
To guarantee quality, a strict inspection is made on all disassembled parts, so both recycled and virgin products are the same, as far as, quality and warranties.

Contact with Universities
There is some contact with universities, such as the University of Tokyo; for example, students go to the remanufacturing facility for visits.

Communication throughout the value chain

Manufacturers
Since FUJI Film manufactures and remanufactures its single-use cameras, a good relation with the manufacturer is kept. When designing the cameras, a large variety is manufactured in order to sell many cameras but they are all adapted for the remanufacturing and recycling processes. Exactly, how this collaboration occurs, however, was not clear. As previously mentioned, concerning distribution in transports is conducted as well as an agreement of where the snapfits should be located.

Adaptations
As mentioned above, the design of the cameras are specified at the snapfits to make it easy for the robots to disassemble the cameras. Since there is a large volume of cameras being processed in the remanufacturing facility, this type of design seems to be crucial. Furthermore, a type of modular design is used. By using this type of design, some interior parts can be used in several types of single-use cameras. Some of the modules can also be used in future designs.

The remanufacturing process could be improved in machine performance in order to reach higher efficiencies in remanufacturing; this is especially valid for the inspection steps.

Obstacles and bottlenecks in the process

Sometimes the interiors of the single-use cameras are damaged. This often calls for manual repairs, which are seen as an obstacle in the remanufacturing process. The most difficult and time consuming is the testing of the flash. There are many inspection points, and as the inspection is increased, more failures can be detected. Analysing and repairing these failures is a very complex process, and they require the most energy and time in the remanufacturing process. Sometimes a manual inspection must be performed for the single-use cameras, which takes an unnecessarily long time. The inspection step is also seen as the bottleneck in the process, since it deals with most parts to assure quality.

As the managers of the facility states, the inspection step is the step that has the most potential to be improved since it includes many precise manual adjustments. Furthermore, the collection of used single-use-cameras could be conducted more efficiently.

Lead times

For the single steps, the process time is about one minute. The total throughput time for the remanufacture a single-use camera is a week, on average. This is due to the fact that the parts/cameras stays are stored between the steps.

Rapid Plant Assessment

No RPA was conducted since there was no possibility to observe the actual remanufacturing process in detail and due to time constraints.

Analysis

The remanufacturing process is highly automated, which affects many parts of the business. The high volumes provide a good driving force for automating the process. High volumes also put requirements on the product design. FUJI Film has made a good compromise between adapting products for remanufacturing and selling new types of designs. Their ‘unit design’ seems to work well for both driving forces.

A problem in their process seems to be the testing of the flash unit. The company should look over its internal part design to make it more adapted to their processes, and the testing of the flash unit could possibly be facilitated. Furthermore, the reverse logistics are important when dealing with these large volumes, and it has been brought up as a crucial area that needs to be addressed. As a part of the reverse logistics, the large numbers of cameras in the warehouses and at the remanufacturing facility are important. The storage of cameras at the remanufacturing facility works as a buffer for evening out seasonal differences. Since FUJI Film has good control over how these changes in volume look like, the remanufacturing volumes could be adapted seasonally and the number of cameras in the buffer storage could be reduced. If this change is possible, or what effect it could have on the business, is unknown.

Case Study at Scania CV AB

Company facts

Name: Scania CV AB
Location: Hantverksvägen 3, Södertälje (Hovsjö), Sweden.
Date for case study: 2004-03-15
Data collection methods:
- Interview with purchaser/manager at the facility
- Rapid Plant Assessment
- Observations

Type of business: Disassembly of heavy trucks

History
Scania's disassembly facility in Hovsjö is relatively new and was opened in January, 2003. There were two reasons why Scania started this business: The first was due to pressure on the company to adapt its organization to comply with forthcoming legislation regarding extended producer responsibilities. Secondly, there were people within the company that were experienced in the disassembly area. Two out of five workers at Scania had experience in truck disassembly from Volvo.

Currently, there is no legislation regarding extended producer responsibilities on heavy trucks in Sweden. According to the facility manager a reason for this could be that both Volvo and Scania currently have these kinds of facilities. There are several disassembly facilities within the Scania Company group, for example in Norway, Finland, Holland, and the United Kingdom. There are some differences between them, for example the facility operating in Norway disassembles both heavy trucks and cars. At the studied facility in Hovsjö, Sweden, heavy trucks are disassembled and the parts are sold rather than reassembled. Scania chooses not to reassemble the heavy trucks since it would compete with their new production.

Organization and personnel
At the facility there are five workers, three of which have a lot of experience in heavy truck repairs. The other two are working with purchasing, selling, and management. The business unit has good support from the company group management. Management gave the business unit five years of free handling before making an evaluation. There are plans to hire two more disassembly workers and certify the facility for ISO9001 and ISO14001 before the end of 2004.

Disassembly process
During the first year of operation 150 heavy trucks were disassembled, of which 80 percent have the Scania brand and the other 20 percent are Volvo heavy trucks (Figure 1). The goal is to disassemble 150-200 heavy trucks per year. The product mix is as follows:

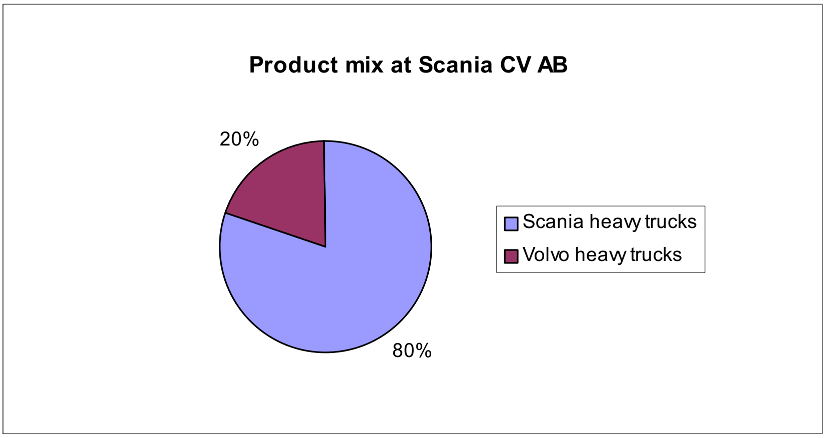


Figure 1. The product mix at Scania CV AB.

The disassembly process is manual and includes the following steps:

1. The purchaser purchases the truck (from Scania's purchase department or from insurance companies)
2. The purchased truck is transported to the facility via a contracted towing company.
3. A standard test is performed on the vehicle and a protocol is written including for example, how the engine sounds and what possible malfunctions may be present.
4. The test results are entered into a database together with the details of the truck's type of use, mileage, purchasing price, and manufacturing year.
5. The truck is transported to one of the facility's disassembly areas where it is disassembled using standard equipment.
6. The truck is emptied on liquids such as glycol, oil, and diesel.
7. Parts with high value (around 50 percent) are put in the database with a unique product number. There are three levels of storage of these parts: Parts, complete engines and chassis, and coachwork. Many of the parts are cleaned before put into storage although certain parts are not in order to prevent rusting of the parts.
8. The diesel is reused and the parts that are not put in any of the three abovementioned storage areas are recycled in any of the following materials categories:
   - Electronics
   - Iron parts
   - Batteries
   - Burnable waste
   - Unsorted waste
   - Glycol
   - Oil
   - Gas from air conditioners

9. Finally, the refurbished parts are sold to any of Scania's retailers.

When the heavy trucks that go into the process are modern (up to 10 years old), many parts are salvaged and the disassembly takes approximately one week. If, on the other hand, the truck is older than 10 years, few parts are salvaged which reduces the disassembly process to one day. For the older trucks it is only the parts 'driving' the engine that are put in storage, e.g., the engine, gearbox, rear gear. The cabins are made of plastics and go to a shredding facility nearby. Scania prefers to have the trucks as complete as possible upon arrival; therefore they do not want to have any pre-disassembly. The facility in Hovsjö has the following layout (Figure 2):

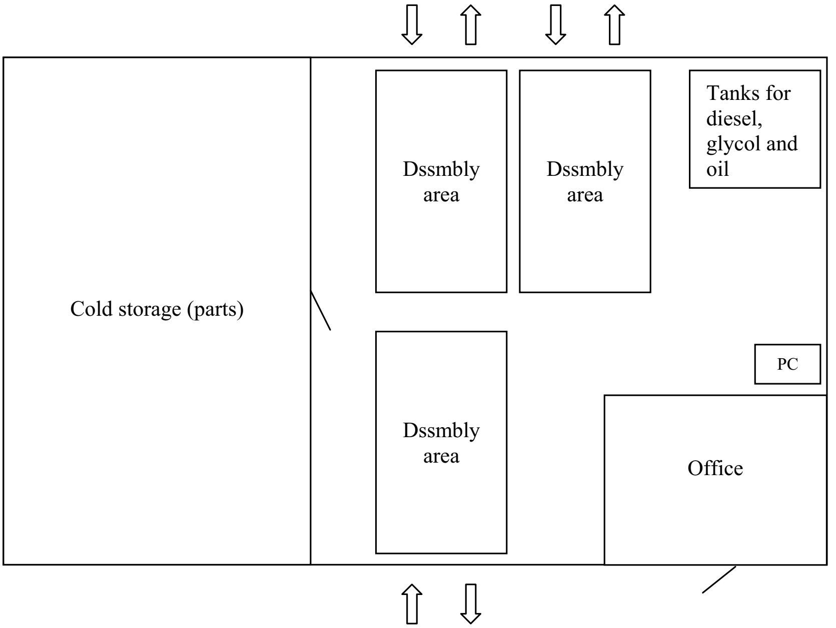


Figure 2. Process layout at Scania CV AB.

Flexibility

The disassembly process at Scania is very flexible since it is manually operated with standard equipment. Furthermore, there is no production line that needs to be adapted depending on the type of truck being disassembled. The yard outside the facility is used as a storage and buffer zone for the incoming trucks (cores).

Product logistics

Each day, there are 20-30 proposals from people who want to sell their used trucks to Scania's disassembly facility in Hovsjö. On average normally only five purchases result from these proposals. As previously mentioned, Scania has an agreement with a towing company transporting damaged trucks to the facility in Hovsjö. Parts are delivered from the facility to the retailers approximately four times per day. It is common to deliver the parts individually but occasionally there is an entire container of parts leaving the facility. There is no available space to store parts in the disassembly areas. The three aforementioned storage areas have the following volumes and throughput times:

Table 1: Times and volumes of storage areas at Scania's disassembly facility.

Storage Area	Volume	Time
Incoming trucks on the yard	80	< 3 months
Part storage – parts	650	< 1 year
Part storage – complete engines & cabins	15 resp. 30	Unknown
Part storage – coachwork parts	300	Unknown

Warranties

In new truck production, the parts come with one-year warranties. For the parts leaving the disassembly facility in Hovsjö, Scania offers the following warranty periods:

Parts in existing condition (right to be returned or money back) – 10 days
Tested parts (no working costs) – 3 months
Refurbished parts (working costs and material) – 12 months

Communication throughout the value chain

Manufacturers

Most of the incoming trucks are manufactured by Scania and their cabin designers have been visiting the disassembly facility in order to assess the performance of their design during the disassembly process. A Korean delegation has been studying the database system.

Customers

The customers obtain information about the parts from the database e.g. type of driving, mileage, purchasing price, and year of manufacture.

Adaptations

The trucks are said to be easy to disassemble and the workers do not have any specific proposals for design changes. Trucks that were manufactured before 1987 are considered more difficult because the cable harness routings in these trucks are badly designed. In the more modern vehicles pipes encase the cables making them more accessible. The cabins have recently also become cleaner e.g., the number of mixed materials has been reduced.

Since the process is quite new, not many changes have been made to date. The facility manager has five years to perform changes in the process as he/she wishes before an evaluation is performed.

Obstacles and bottlenecks in the process

According to the facility manager, it is the actual disassembly step that represents the longest time in the disassembly process (see the steps above). This step is therefore the most costly due to the high cost of man-hours. Another costly phase in the process is the revenue loss resulting from the materials that cannot be reused. It costs approximately 3000 SEK per container to dispose the waste. The facility manager has not identified any obstacles in the process nor steps, which could be optimised. A possible constraint/bottleneck is the space limitation. At the facility there are only 3 disassembly areas, which limits the opportunity to increase volume. More disassembly areas could yield a higher production volume.

Working environment

The facility was recently constructed, and is considered to be one of the most modern disassembly facilities in the country. The disassembly hall has a sophisticated environmental control system, which maintains a comfortable working. Ambient noise levels appear to be low. The working conditions are occasionally dirty but that is inevitable given the nature of the task of disassembling used trucks. The working hours are 07.00 to 16.00.

Table 1. Operation times.

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Process step	**Operation time (in time)**	**Operation time (in percentage)**
Testing	X min	
Input to database	X min	
Transport to disassembly area	X min	
Disassembly	0,5 – 7 days	
Emptying liquids	X min	
Cleaning	X min	
Transport to storage	X min	
Total		**100 %**

Rapid Plant Assessment

In the RPA, Scania scored well in the areas of managing flexibility, customer satisfaction, quality and team work. The work force is very flexible and can chose to disassemble any kind of truck that needs to be disassembled at the moment. The process is totally manual and the work at the three disassembly areas is carried on independent of each other. Scania got lower scores for product flow, inventory levels which can be related to the type of business and low remanufacturing volumes. Furthermore, the product being remanufactured, in this case, trucks are quite complex and high volumes are hard to achieve. The total RPA score for the facility was 57. The rapid plant assessment for Scania had the following results (Figure 3 & 4):

Plant	Rapid Plant Assessment at Scania CV AB (Hovsjö) Date 2004-03-15	apr-02
No	Table 2--Assessment Questionnaire	Yes/No
1	Are visitors welcomed and given information about plant layout, workforce, customers, and products?	Yes
2	Are ratings for customer satisfaction and product quality displayed?	No
3	Is the facility safe, clean, orderly, and well lit? Is the air quality good and noise levels low?	Yes
4	Does a visual labeling system identify and locate inventory, tools, processes, and flow?	No
5	Does everything have its own place, and is everything stored in its place?	Yes
6	Are up-to-date operational goals and performance measures for those goals prominently posted?	No
7	Are production materials brought to and stored at line side rather than in separate inventory storage areas?	No?
8	Are work instructions and product quality specifications visible at all work areas?	Yes
9	Are updated charts on productivity, quality, safety, and problem solving visible for all teams?	No?
10	Can the current state of the operation be viewed from a central control room, on a status board, or on a CRT?	No
11	Are production lines scheduled off a single pacing process with appropriate inventory levels at each stage?	No
12	Is material moved only once as short a distance as possible and in appropriate containers?	Yes?
13	Is the plant laid out in continuous product flow lines rather than in "shops"?	No
14	Are work teams trained, empowered, and involved in problem solving and ongoing improvements?	Yes
15	Do employees appear committed to continuous improvement?	Yes
16	Is a timetable posted for equipment preventive maintenance and continuous improvement of tools and processes?	No
17	Is there an effective project management process, with cost and timing goals, for new product start-ups?	Yes
18	Is a supplier certification process--with measures for quality, delivery, and cost performance--displayed?	No
19	Have key product characteristics been identified and fail-safe methods used to forestall propagation of defects?	No
20	Would you buy the products this operation produces?	Yes
	Total number of Yeses	9

Figure 3: RPA questionnaire

Rated by: _Erik Sundin Tour Date: _2004-03-15		Rapid Plant Assessment Table 1--Rating Sheet				Plant: __Scania CVAB	apr-02
	Ratings →	Poor	Below Average	Average	Above Average	Excellent	Best in Class	
No	Measure ↓ Score →	1	3	5	7	9	11	Scores
1	Customer Satisfaction				x			7
2	Safety, environment, cleanliness, & order			x				5
3	Visual Management Deployment		x					3
4	Scheduling system		x					3
5	Product flow, space use & material movement means		x					3
6	Inventory & WIP Levels		x					3
7	People teamwork, skill level, & motivation				x			7
8	Equipment & tooling state & maintenance			x				5
9	Ability to Manage Complexity & Variability					x		9
10	Supply Chain Integration			x				5
11	Quality System Deployment				x			7
	Totals →							57

Figure 4: RPA Worksheet

Company analysis

Scania is an original equipment remanufacturer, which uses the knowledge of the other parts of the company. Designers have been evaluating the own designs in the disassembly process. The collaboration is not used in full since the trucks are not reassembled. This is due to the fact that Scania does not want to compete with remanufactured trucks on the same market as their new manufactured trucks. As the products looks today they are relatively easy to manufacture. Changes have been done over the years and Scania's modularise thinking works well for the disassembly process. The most time consuming parts of the process is the disassembly. High labour costs make this part relatively expensive. The disposal of materials and liquids is a part that gives high costs. The bottleneck in the process is that there are only three disassembly areas to disassemble at which reduces the possibilities for higher volumes. There are plenty of cores to buy and the amount of customers is rising. The database for remanufactured products will grow and the personnel are making it easier to buy the remanufactured parts.

Case Study at Electrolux AB

Company facts

Name: Electrolux AB
Location: Motala, Sweden.
Date for case study: 2004-05-18
Data collection methods:

- Interview with the facility manager
- Interviews with personnel
- Rapid Plant Assessment
- Secondary data from ABC-calculations
- Secondary data from student reports
- Observations

Type of business: Household Appliance Remanufacturer.

History

Electrolux AB began to remanufacture their products in a facility in Motala, Sweden in 1998. The driving force for this facility was mainly environmental, although economical benefits for the company, retailers and the market (consumers) were also important. Furthermore, functional sales worked as a potential driving force to start the remanufacture of products. Since earning a profit from these activities was uncertain from the start, it was decided to put the remanufacturing process in a seldom used warehouse near an ordinary manufacturing plant for stoves. The equipment for the process consists of old machines that are no longer useful in ordinary manufacturing. Since the remanufacturing process is currently earning a profit, and since this supports the company's environmental profile the facility is still in operation with increasing volumes. Today the remanufacturing volumes are around 5 500 annually.

Electrolux has other remanufacturing facilities for household appliances in Luton (England) and for garden equipment in U.S.A. Also, there is a business in Lithuania for disassembling vacuum cleaners in cooperation with a domestic school. The facility does not have any ISO certificates, although the nearby oven-factory holds an ISO9001 certificate. There is some legislation related to the business, e.g. the extended producer responsibility, but it was not a driving force to start the remanufacturing business.

Remanufacturing process

At present, 7 500 products arrive at the Motala facility annually from throughout Scandinavia (Figure 1). Approximately 1 500 of these are not worth the cost of further remanufacture, and are thus stored for part and component recycling. Another 500 products leave the remanufacturing process, since they contain severe damage and are therefore not worth further remanufacture. That means that 5 500 remanufactured household appliances leave the facility annually, as shown in Figure 1 below.

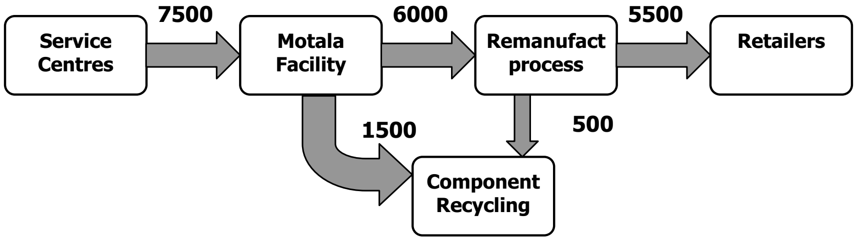

Figure 1: The product flows at the Electrolux remanufacturing facility in Motala, Sweden.

Most of the products that arrive at Motala are newly manufactured with failures covered by warranties and which servicemen have not been able to repair on site. Moreover, products that have damage from transport and products used for leasing are also remanufactured at the facility. The mix of household appliances delivered to the facility is shown in Figure 2 below.

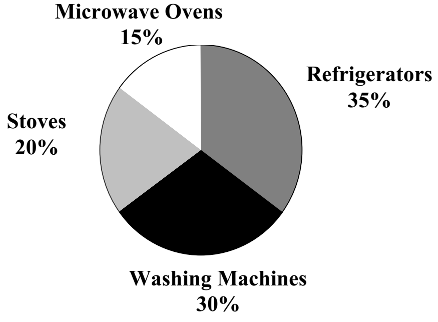

Figure 2: The mix of products for the facility in Motala.

Once the products arrive in Motala, they are registered into a database, after which they will be subject to a standard set of procedures:

1. Test and safety control
2. Exchange of components and repairs
3. Clean-up (outsourced to a cleaning professional)
4. High voltage test
5. Marking with new serial number
6. Packaging the product

The layout of the Motala facility is displayed in Figure 3.

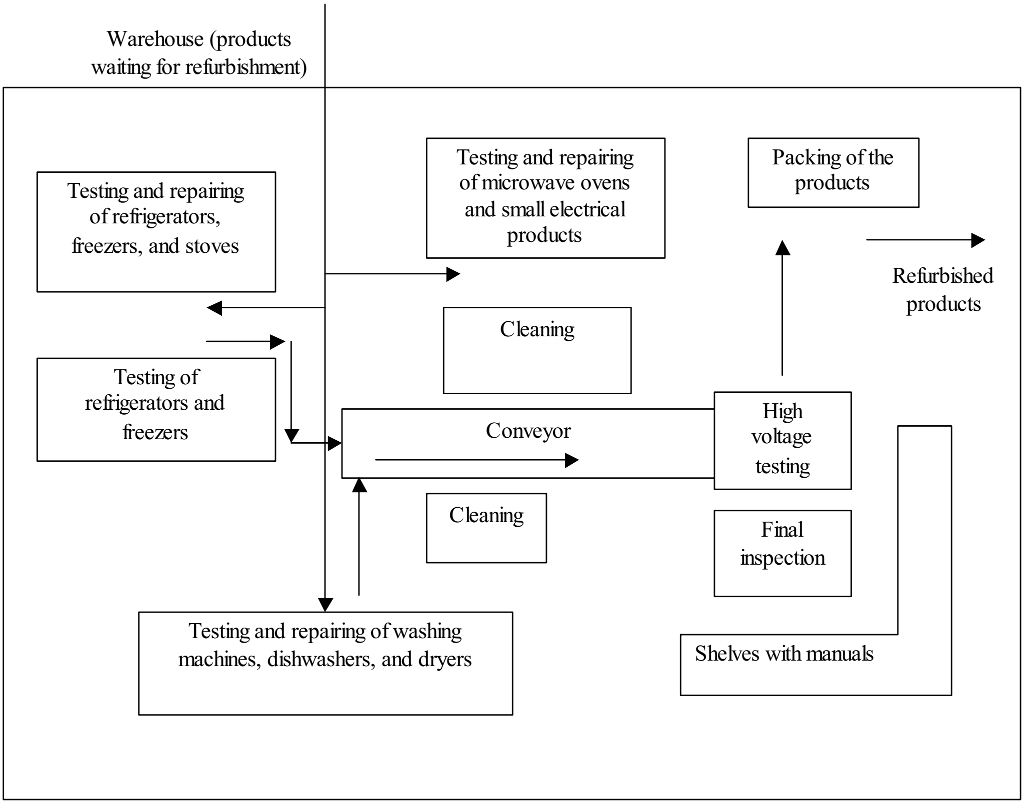

Figure 3: Process layout at Electrolux AB, Motala.

The process is station based although the stations are laid out in logical flow sequence. Between the cleaning and high voltage testing, a roll conveyor is used (see Figure 4 below).

Figure 4. Roll conveyors for transporting appliances on between cleaning, high-voltage testing and new marking.

Organization and personnel
On the floor, there is one first man and four repairmen, each which has own responsibility. Each person has the main responsibility for one type of product, but have the ability to perform the work of others as well. One woman is in charge of the high voltage testing for all of the appliances. A cleaning firm performs the cleaning step.

Automation
There are very few automatic steps in the remanufacturing process. Machines used are for testing the refrigerators and the computers having the products in the database. When volumes are higher it could be useful to have a database for the spare parts held in storage and to automate the cleaning process.

Flexibility
The facility is highly product flexible, since the system for personnel allows people to work with different products each day. From start, the workers are specialized on one type of product, but have the knowledge to work with other products as well. There is also flexibility in the storage levels. Some products, such as freeze boxes are saved for refurbishment during the autumn, when it is hunting season in Sweden. In the same manner, smaller refrigerators are saved until it is summer. These examples are due to the seasonal changes in customer demand.

Product logistics
Electrolux has a contracted logistics company, which handles the logistics of appliances coming in and out of the facility. The outgoing appliances are stacked in the facility by Electrolux to reduce the amount of transport damage. This damage was difficult to spot in comparison with the damages the remanufactured products already had from the first use period, which is why

Electrolux now does the stacking. The appliances are ordered by the retailers in groups of twelve or more.

Legislation

There is legislation for extended producer responsibility affecting the product take-back of household appliances in Sweden, although this has not been a driving force for the refurbishment facility in Motala.

Warranties

The same kinds of warranties are given for the refurbished products as for the newly manufactured ones. A service guarantee is given for the remanufactured products for 1 year. The same guarantee is given for 2 years for newly manufactured products. It has been shown that, in average, rates of products returning to Electrolux are 50 percent lower for the refurbishment plant than for the ordinary manufacturing plants.

Contact with Universities

Electrolux has had several instances of cooperation with researchers and students from Linköping University. This has been in the form of student projects and participation as the industrial partner in research projects. Furthermore, students from the Royal Institute of Technology have had contact with the facility in Motala.

Communication throughout the value chain

Manufacturers

Product designers have good contact with the refurbishment facility. For example, designers from Italy come to analyse how their designs work in the refurbishment process. In addition, a good contact with the manufacturing facilities in Motala and Mariestad (Sweden) is maintained. Furthermore, manuals for the appliances are ordered from the manufacturers.

Customers

The customers for Electrolux are the retailers used for selling products from the ordinary manufacturing. Each Friday, a list of which appliances the Motala facility has in its refurbished appliance storage is mailed to the different retailers. Before Wednesday the following week, orders arrive at Electrolux. The appliances then reach the retailer before the weekend. The end-users (retailer customers) will buy the refurbished appliance which are marked as refurbished and with a note explaining that they have been refurbished, as shown in Figure 5.

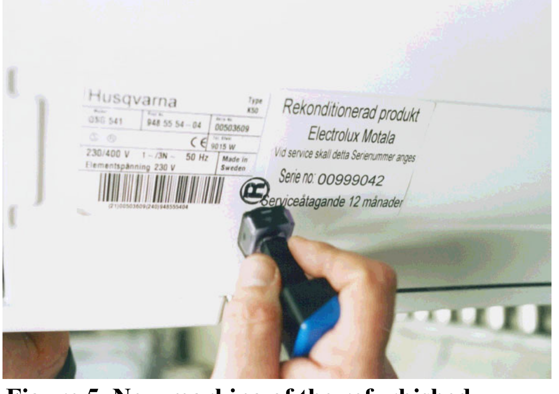

Figure 5. New marking of the refurbished products.

Adaptations

The appliances can be better adapted for the refurbishment process, as the student reports from Linköping University showed. More examples are that the appliances need to be designed to withstand the cleaning step, e.g. cleaning liquids and utilities.

If the volumes were higher, some parts of the process could be made more automatic. For example, a washing line for laundry machines could be implemented; this has been practiced looking like a small car wash. In this case, some parts needed to be taped to hinder leakage of water into the washing machines.

Obstacles and bottlenecks in the process

The cleaning step is most expensive and time-consuming step in the refurbishment process at Electrolux. A limitation in the process is the asset of incoming product cores. Some models need to be available on specific country markets, including spare parts. A bottleneck in the process might, according to the facility manager, be the high-voltage testing. Since volumes are quite low, this is not seen as a large problem. In order to make the business more profitable much can be earned by having it moved, for example, to eastern Europe, were salaries are much lower than in Sweden.

Working environment

The facility is well lit and kept clean, although some leakage occurs from the testing programs of washing machines. Forklift trucks, sack wagons and roll conveyors are used to transport the appliances; which appears to be a good way of moving the products. The sound levels in the facility are also low.

Lead times

Products enter the Electrolux facility steadily. At first, they are unloaded and registered in a database, which takes about 3 minutes per product. Secondly, they are put into an 'incoming product storage area' where they can stay from 0 to 90 days before being processed. This is due to the product's possibility to be sold on the market. When entering the 'real' remanufacturing process following operation times exit for the various products:

Table 1: Operation times (OTs).

Remanufacturing Step	Refrigerators		Microwave Ovens		Stoves		Washing Machines	
	OT in Time	OT in %	OT in Time	OT in %	OT in Time	OT in %	OT in Time	OT in %
Testing	24 h	95	-	0	-	0	80 min	57
Exchange & Repairs	20 min	1	20 min	40	20 min	50	20 min	14
Cleaning	45 min	3	20 min	40	10 min	25	30 min	21
High-Voltage	4 min	0,5	4 min	8	4 min	10	4 min	3
Marking	1 min	0	1 min	2	1 min	2,5	1 min	1
Packaging	5 min	0,5	5 min	10	5 min	12,5	5 min	4
Total	**1515 min**	**100**	**50 min**	**100**	**40 min**	**100**	**140 min**	**100**

Finally the products go to a "refurbished product storage", where they stay from 0 to 30 days before being shipped to any of the 20, selected retailers.

Activity Base Cost analysis
In a related master student project, an economic analysis was performed during 2001, the result of which is shown in Figure 6.

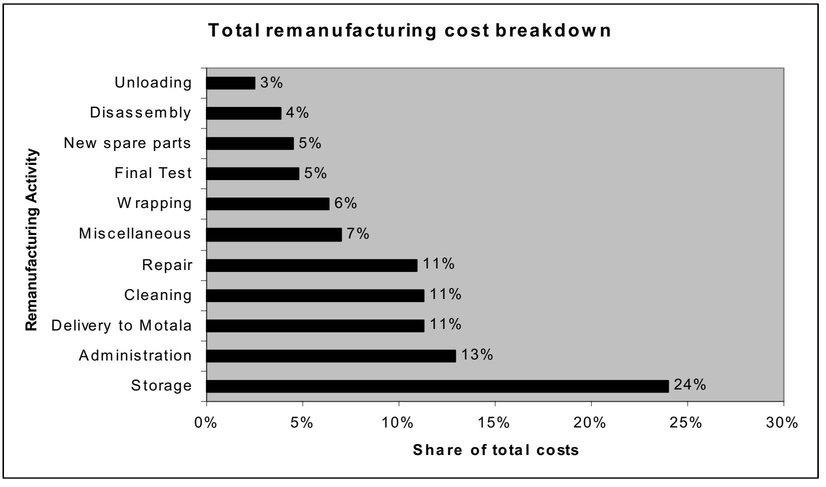

Figure 6: The total remanufacturing breakdown at Electrolux AB, Motala, 2001.

Since there are three storage areas in the facility where the products are held in storage, sometimes for days, it is not surprisingly that it has the largest share of the remanufacturing costs, as illustrated in Figure 6 above. Calculated in the cost of storage is the storage of incoming products, outgoing products and spare parts. Since this share is large, one might consider ordering new spare parts instead of storing the incoming products (cores). This decision is, of course, dependent on how much space is available for storage, and how high the rent for that space is. Administration has also a large cost share, and consists mainly of salaries and the computer system used to keep track of the products. This share will probably decrease as volumes and yields in the remanufacturing plant increase. Cleaning and repairing the products have the two largest shares of costs besides storage in the actual remanufacturing process.

Rapid Plant Assessment

The answers to the RPA questionnaire show 10 yeses, while the rating sheet total was 57. Most of the categories in the rating sheet were marked around average. The RPA shows that Electrolux has good quality on their refurbished appliances, although they have high levels of inventories. Since the inventory space rent is rather low, this is not considered as a high cost, and not of importance to reduce. The work force is motivated and committed to quality.

Plant	Electrolux, Motala Rapid Plant Assessment Date 2004-05-18	
No	Table 2--Assessment Questionnaire	Yes/No
1	Are visitors welcomed and given information about plant layout, workforce, customers, and products?	Yes
2	Are ratings for customer satisfaction and product quality displayed?	No
3	Is the facility safe, clean, orderly, and well lit? Is the air quality good and noise levels low?	Yes
4	Does a visual labeling system identify and locate inventory, tools, processes, and flow?	No
5	Does everything have its own place, and is everything stored in its place?	No
6	Are up-to-date operational goals and performance measures for those goals prominently posted?	Yes
7	Are production materials brought to and stored at line side rather than in separate inventory storage areas?	No
8	Are work instructions and product quality specifications visible at all work areas?	Yes
9	Are updated charts on productivity, quality, safety, and problem solving visible for all teams?	Yes
10	Can the current state of the operation be viewed from a central control room, on a status board, or on a CRT?	No
11	Are production lines scheduled off a single pacing process with appropriate inventory levels at each stage?	No
12	Is material moved only once as short a distance as possible and in appropriate containers?	No
13	Is the plant laid out in continuous product flow lines rather than in "shops"?	Yes
14	Are work teams trained, empowered, and involved in problem solving and ongoing improvements?	Yes
15	Do employees appear committed to continuous improvement?	Yes
16	Is a timetable posted for equipment preventive maintenance and continuous improvement of tools and processes?	Yes
17	Is there an effective project management process, with cost and timing goals, for new product start-ups?	No
18	Is a supplier certification process--with measures for quality, delivery, and cost performance--displayed?	No
19	Have key product characteristics been identified and fail-safe methods used to forestall propagation of defects?	No
20	Would you buy the products this operation produces?	Yes
	Total number of Yeses	10

Figure 7. RPA questionaire for Electrolux, Motala.

Rated by:__Erik Sundin__
Tour Date:_2004-05-18__

Rapid Plant Assessment
Table 1--Rating Sheet

Plant:__Electrolux, Motala

	Ratings →	Poor	Below Average	Average	Above Average	Excellent	Best in Class	
No	**Measure ↓ Score →**	**1**	**3**	**5**	**7**	**9**	**11**	**Scores**
1	Customer Satisfaction				x			7
2	Safety, environment, cleanliness, & order			x				5
3	Visual Management Deployment		x					3
4	Scheduling system		x					3
5	Product flow, space use & material movement			x				5
6	Inventory & WIP Levels		x					3
7	People teamwork, skill level, & motivation				x			7
8	Equipment & tooling state & maintenance				x			7
9	Ability to Manage Complexity & Variability			x				5
10	Supply Chain Integration			x				5
11	Quality System Deployment				x			7
	Totals →	0	9	20	28	0	0	57

Figure 8. RPA rating sheet for Motala.

Analysis

The refurbishing facility that Electrolux operates in Motala is rather young. Although it is labour intensive and has relatively small remanufacturing volumes, it is showing profit. According to the facility manager, it would be more profitable to have this operation in a country with lower salaries. Today, there are many inexpensive appliances on the market, which remanufactured appliances from the facility compete with.

Cleaning is the remanufacturing step that needs to be improved the most according to the data collected. To increase efficiency in this step, the following actions can be taken:

- Install steam cleaning.
- Train personnel so that they become more task-flexible, i.e. personnel from other work areas can ease the cleaning step by doing some kind of pre-wash when needed.
- Design products that do not collect dirt in the first place.

Many of the steps can be facilitated through improved product design. In some cases, more effort to adapt the product for remanufacturing, could be of value, instead of making changes in the process. As it looks today, the personnel are flexible and have good knowledge of how to repair many different types of appliances. There is also a high degree of flexibility due to the storage capacities in the facility, which the facility manager uses for the seasonal changes in demand.

Although there is a database of the products in storage, there are no records of which spare parts are held in stock; this information is only in the heads of the remanufacturing personnel. This could be a problem when the staff is sick or when remanufacturing volumes increase. Today, however, this situation is not a problem.

The refurbishment operation is good for Electrolux since it contributes to the company's environmental image, and shows profit. Furthermore, many appliances that earlier could not be repaired on site are now refurbished and sold to retailers once again. This option of end-of-life treatment is one of the best possible for an appliance company as Electrolux.