Making functional sales environmentally and economically beneficial through product remanufacturing

Erik Sundin and Bert Bras

Original Publication:

Erik Sundin and Bert Bras, Making functional sales environmentally and economically beneficial through product remanufacturing, 2005, Journal of Cleaner Production, (13), 9, 913-925.
http://dx.doi.org/10.1016/j.jclepro.2004.04.006

Making Functional Sales Environmentally and Economically Beneficial through Product Remanufacturing

M.Sc. Erik Sundin*
Linköping University, Department of Mechanical Engineering, Division of Production Systems SE–581 83 Linköping, Sweden.

Dr. Bert Bras
Georgia Institute of Technology, George W. Woodruff School of Mechanical Engineering, Systems Realization Laboratory, Atlanta, Georgia, 30332-0405, U.S.A.

Abstract
Functional sales has both economic and environmental benefits - especially when the functional sales contracts are used in connection with product remanufacturing. This paper elucidates these benefits and provides an argument for why products to be used for functional sales should be remanufactured. To achieve an efficient remanufacturing process, the products aimed for remanufacturing should be adapted for the process as much as possible. The analyses of remanufacturing facilities for household appliances and automotive parts showed that the cleaning and repairing steps are most critical in the remanufacturing process. To facilitate these two steps, the product designers should focus on giving the products the following properties: *ease of access*, *ease of handling*, *ease of separation* and *wear resistance*.

Keywords:
Functional Sales, Service Selling, Remanufacturing, Design for Environment, Ecodesign, Design for Remanufacturing and Activity Based Costing (ABC).

1 Introduction

The present rate of extraction of material from the earth's crust is not sustainable. This unsustainablility is not only due to the depletion of resources, but also to the waste problems that are related to the extraction that makes it unsustainable. In order to reach a state of sustainable development, (i.e. a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]) mankind needs, to a larger extent, to close these unsatisfactory material flows. This can be partially achieved by a larger degree of product recovery, e.g. product remanufacturing. In line with this, the European Union is in the process of passing a new directive, the WEEE (directive on Waste Electrical and Electronic Equipment), which deals with the growing problem of electrical and electronic waste. As production and use of electrical and electronic equipment has grown, there has also been a rise in the disposal of such equipment. The *polluter pay principle* (PPP) has been applied in seeking to implement this directive, ensuring that manufacturers are involved in the reduction of

* Corresponding author: E-mail: erik.sundin@ikp.liu.se, fax: +46-13-282798.

wasteful consumption of natural resources and pollution. Furthermore, in some countries, for example Sweden where most of this research has been conducted, there are laws for producer responsibilities. As the directive is formulated today, it includes several product types such as electrical products except refrigerators.

Another means of closing the material flows is to focus on functional sales instead of selling physical products; a condition for this is that the hardware used in association with the service is reused, either as is or after it has been remanufactured or recycled[I]. Moreover, the production and processing of raw material is decreased when the hardware is remanufactured. Thus, by having a strategy for both functional sales and remanufacturing of products, both environmental and economic benefits can be achieved. Having a remanufacturing perspective on functional sales, and vice versa, with a connection to product design, is a new way of looking at these concepts. This could give the manufacturing/remanufacturing company new market shares for its products. The concept of functional sales is further described in the next chapter.

This research does not include any environmental calculations of whether the remanufacturing of products is environmentally benign or not. On the other hand, there are many guidelines, recommendations and estimations of environmental character, which describe remanufacturing as an ecologically preferable option in comparison with other end-of-life options, e.g. recycling, incineration and landfill [5, 6, 7, 8 and 9]. Hence, this paper focuses on technical and economic aspects of remanufacturing.

Although many researchers have investigated the concept of remanufacturing and design for remanufacturing (see [3] for an overview), relatively few have looked deeper into the remanufacturing process to find out what kinds of requirements the process places on the products, and how to couple remanufacturing with functional sales. Furthermore there exist a limited number of case studies in remanufacturing literature [4]. Given this, the objective of this study was to investigate and evaluate in what manner products can be designed in order to facilitate remanufacturing and functional sales. The approach to fulfil the objective was divided into the following three research tasks:

1. Determine the steps that are to be included in a generic remanufacturing process and the product properties required.
2. Analyze remanufacturing processes both technically and economically.
3. Elucidate which product properties are essential for the remanufacturing process, from both economic and technical perspectives.

In order to fulfill the research steps above, an extensive unpublished literature study was conducted within the areas of functional sales, remanufacturing and design for 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, complimented with other remanufacturing processes described in the literature. The remanufacturing process was analyzed from both a technical and economic

[I] For a thorough survey on what research that has been conducted within the area of environmentally conscious manufacturing and product recovery see [2].

perspective through interviews with remanufacturing personnel and remanufacturing process monitoring. The economic analysis was conducted using an activity-based costing method (ABC), which is relatively new in this kind of research. Case studies of ABC calculations at remanufacturing facilities are described in [10], [11] and [12]. Furthermore, two household appliances were analyzed from a remanufacturing perspective to determine to what extent the products were adapted for remanufacturing and to suggest design changes to facilitate remanufacturing. This paper begins with a short description of the concepts of *functional sales* (with the example of BT Industries) and *remanufacturing,* and includes a generic remanufacturing process. The essential product properties connected to the steps are presented in a Matrix called RemPro (Figure 5). Secondly, two industrial remanufacturing process case studies of the remanufacturing of household appliances and automotive parts are described.

2 Functional Sales

The phenomenon of functional sales has become more prevalent in current consumer patterns and its emergence is mainly market-driven. In functional sales, a very strong focus is placed on how to fulfil customer needs and create customer value [13]. Although the idea is also named in literature and practice as *"functional sales/economy"*, *"product service combinations"*, *"product-to-service"*, *"servicizing"* and *"product service systems (PSS)"*, the authors most often mean the same thing [14]. Today, value is added to products by technological improvements, but also through immaterial aspects such as intellectual property, product image and brand names, aesthetic design and styling. These aspects help producers to differentiate and diversify their products to better respond to customer's demands. This means a change from mass production to mass customisation [15]. According to Kimura [16], a paradigm shift is needed to change from traditional product selling to more service oriented products sales. In addition, the traditional boundary between manufacturing and services is becoming increasingly blurred [15]. In functional sales, the service-providing company decides how to fulfil the function that the customer is buying, whereas in leasing the physical product used for the function is known or specified by the customer. Renting a product is even more linked to a specific physical product. These different forms of providing the customer with their desired demands are be illustrated in Figure 1.

<Insert Figure 1 here>

Within functional sales, the function-providing company decides how to fulfill the function that the customer is buying, whereas in leasing the physical product used for the function is known by the customer (see Figure 1). In the cases of renting, leasing and functional sale, the product is not sold and a contract is written between user and provider. This contract is more advanced for the functional sale concept. Leasing is a contract form, which often is used for financial reasons, as products are often sold to the customers who leased them when the contract has run out.

An example of functional sales is when a company provides the function of washing clothes instead of the actual washing machine. The customer, in this example, only pays for the number of laundry loads used, instead of purchasing the washing machine itself.

Functional sales has the potential to be environmentally benign, as it addresses current levels of material consumption while seeking options that may provide functions to the consumer, without minimizing their level of welfare [15]. In the previously mentioned laundry case, the machines could be filled more efficiently since there was an economic incentive for the user, which also decreased the overall water and power usage.

When providing a function instead of a product, a contract must be signed between the customer and the service provider. Here, the connection between the stakeholders becomes more formal and the contracts that regulate what the offer includes are of importance [13]. Thus, if the manufacturing company provides the function, then it becomes increasingly knowledgeable about how its products perform during use. This product control can be achieved through web monitoring, and thus facilitated by today's information technology. Monitoring the product for the purpose of functional sales allows the company to learn more about how it performs throughout its life cycle. If the product is returned to the manufacturer for remanufacturing, it is possible to evaluate how the product has performed throughout its lifecycle and what needs to be improved. This knowledge allows the manufacturer to improve its products accordingly, e.g. reduce the need for service throughout the user phase, discover latent design errors more quickly and obtain better knowledge of how the product is used.

Only a few products manufactured today are adapted for remanufacture. This is sometimes due to the optimization of the manufacturing process, e.g. products are designed to be assembled as quickly as possible without facilitating disassembly. Products that are subject to service, however, are more amenable for remanufacture. It is not surprising, therefore, that products like aircraft engines (e.g. from General Electric), construction equipment (e.g. from Caterpillar), and automotive components are readily remanufactured. A preferable precondition for the functional sales concept is that the products are designed for remanufacturing and repair while it can be environmentally and economically advantageous to use existing product designs for service hardware, it is better to have products specifically designed for this purpose. The hardware must be designed in accordance with the specific environmental and technical constraints and possibilities of the functional sales approach. The hardware, to a greater extent, must be designed for total long-life use in order to decrease any negative environmental impacts. The customers must accept this long-life aspect in order to make the transition to functional sales economically feasible. Therefore, hardware designed for long-life must also allow modernizing and upgrading from a consumer point of view in order to achieve high customer value, as customers will not accept hardware that they feel is at risk of becoming obsolete or unfashionable. Another reason for designing products for regular upgrades is that less efficient technologies (e.g. from an environmental point of view) can be replaced. It is important to point out that not all hardware, e.g. slim and cheap cellular phones, should be designed for long-life use since they will only be on the market a shorter time. Rather, this aspect must be considered and investigated from the economic, environmental and technical standpoints.

A company that has adopted a business strategy, which is close to the functional sales strategy previously described, is BT Industries. This Swedish forklift manufacturer, which sells many forklifts on a long-term rental basis, will be further described in the following section based on interviews at BT Industries[II].

2.1 BT Industries

2.1.1 Long-term Rental at BT Industries

BT Industries (BT), which has its headquarters in Mjölby, Sweden, is one of the world's leading suppliers of forklifts. Functional sales, or long-term product rental, is according to BT the ideal contract for a company that wants to concentrate resources on its core business instead of selling the actual forklift, the function of the forklift is sold. When offering goods/physical products, as in the case of BT's forklifts, it is often clear what the purchase includes. When providing a function, however, it becomes more complex, and thus a more formal contract must be established. This leads to a closer connection between the end-users and the manufacturing company (if the manufacturer provides the function) as well as better knowledge about how the company's products perform during use. The following areas are included in the agreement between BT and the customer:

- Financing (including spare parts)
- Service
- Maintenance

This describes the case of BT, though these areas could be complimented at other companies with additional areas such as upgrading and end-of-life. Furthermore, some restrictions could be added to the contract. For example, if the floor where the forklift will operate is very dirty, the agreement may exclude the service and maintenance of the forklift wheels; in this case, the customer pays for wheel replacements. Combined working conditions such as floor cleanliness, temperature changes and driver performance tend to significantly affect the operational costs for the forklifts. It should be noted that the forklifts are not designed for service, but rather in a manner that facilitates quick part changes.

One of the reasons why BT uses a long-term rental approach is that it wants to provide its customers with a forklift function at the lowest price. This has worked satisfactorily for most cases of long-term rental for both BT and its customers. The company's customers can decide configuration parameters such as *number of pallets*, *height of storage* and *storage capacity*, and enter these into a software program which then provides the customer as an output, which type of forklift is most suitable. Also, BT personnel conduct customer company visits to make suggestions in order to better and more efficiently meet the customer's demand. Hence, BT claims that its customers should focus on its core competencies, and leave the responsibility of storage handling with forklifts to BT. Moreover, the customer avoids the risks of ownership, consumes less capital, gains flexibility and improves their ability to predict costs [17].

[II] Interview with Christer Saleteg (and some of his staff), Vice President Eurodeals, BT Europe, christer.saleteg@bt-europe.com, +46-142-86715, 2001-10-05.

2.1.2 Remanufacturing at BT Industries

All forklifts delivered to Swedish customers through any kind of rental program may be returned to BT for remanufacturing at any stage of their functional life; this means that there are costs to salvage by designing the forklifts for remanufacturing. The remanufacturing personnel only know where the forklift has been used and for how long. At remanufacturing, worn parts are replaced and the chassis is repainted due to the scratches accumulated during use. One problem, according to the remanufacturing personnel with the refurbishment of the forklifts, is that the users often put many stickers on the forklift, which are difficult to remove.

At present, approximately 1,000 forklifts are remanufactured annually at BT's facility in Mjölby, Sweden. Of these, BT resells 60 percent for short-term lease, while the other 40 percent are either resold by other dealers or material recycled, as shown in Figure 2 below. BT aims at changing those figures to 80 and 20 percent, respectively.

<Insert Figure 2 here>

During material recycling, valuable parts like engines, oil and batteries are removed before being sent to a material recycling company, Gotthards-Ragnsell, for further recycling. The number of products remanufactured at BT is likely to increase, since the number of forklifts being sold through rental programs is increasing steadily. At present, there are 27,000[III] forklifts in rental programs throughout Europe, which will likely lead to an increase in the incoming number of forklifts to the remanufacturing facility. Forklifts that are older than 8 years are not considered for remanufacturing, and thus are material recycled. Primarily, BT tries to resell the remanufactured forklifts on a short-term rental basis, which is a lucrative rental approach for BT. Few forklifts receive enough complaints leading to warrant remanufacture, as the remanufactured forklifts that are 5 years old work almost as well as newly manufactured forklifts, if the battery is replaced. The remanufacturing system is currently not adapted for remanufacturing a high volume of forklifts, however, and the products are not designed for remanufacturing. At present, the forklifts are designed for ease of part replacement.

In conclusion, since BT Industries has a business strategy similar to functional sales and a remanufacturing facility near its manufacturing i Mjölby, there are many potential revenues to achieve. In order to make its business more beneficial, the product information should be accessible for the remanufacturing personnel and the products should be adapted for the remanufacturing process, which also should be upgraded for the larger volumes of forklifts to be remanufactured in the future.

Remanufacturing is a basis for an innovative paradigm shift in the manufacturing industry - from selling physical products to supplying services through product systems - as shown in Figure 1 above [16]. Kimura [16] states further that *"it is obvious that the concept of service selling based on remanufacturing will be a definite solution for our*

[III] In this sentence *present* means October 2001.

environmental problems caused by manufacturing". Hence, remanufacturing is a natural part of the functional sales concept, and will be further described in the next chapter.

3 Remanufacturing

Remanufacturing is not a new phenomenon, since it has been used in industry for some time, especially in the automotive industry. As an environmentally motivated concept and with a coupling to functional sales, however, it is relatively new. One of the first researchers in this area was Robert Lund, who provided remanufacturing advice to potential remanufacturers in the late 1970s and early 1980s [3] (see for example; [18, 19 and 20]). The concept is now breaking through to other industries, initiated by customer demands, economic revenues, environmental company policies and legislation, both present and future, e.g. extended producer responsibility and WEEE. Remanufactured products can be restored to original specifications or be modernized and upgraded to new specifications. Hence, remanufacturing promotes the multiple reuse of materials and also allows manufacturers to upgrade the quality and the functions of their products steadily, without manufacturing completely new products and disposing of used ones.

There are different definitions for the term “remanufactured”. The US Automotive Parts Rebuilders Association (APRA) states “*Remanufacturing is the process of restoring worn and discarded durable products to like-new condition*.” In this study, remanufacturing is defined as "*the process of rebuilding a product, during which: the product is cleaned, inspected and disassembled; defective components are replaced; and the product is reassembled, tested and inspected again to ensure it meets or exceeds newly manufactured product standards"* [12].

If the remanufacture of the product is not extensive, i.e. few parts are replaced, either of the terms reconditioning or refurbishing are more suitable. Reconditioning typically refers to the restoration of parts to a functional and/or satisfactory condition by surfacing, painting, sleeving, etc. [21]. In addition, some researchers use the term reconditioning/refurbishing when the product is only remanufactured to its original specification without exceeding them [22]. Also, the steps in the remanufacturing process could be put into different order, or some steps could even be omitted, depending on the product type, remanufacturing volume etc. The following steps have been determined, based on the literature study, for inclusion in the generic remanufacturing process shown in Figure 3 below:

<Insert Figure 3 here>

Kerr and Ryan [9] present a more thorough description of a generic remanufacturing process. The remanufacturing companies have different remanufacturing strategies to choose from. Either the products are totally disassembled, and thereafter error detection is conducted, or the inspection occurs as the first step, with the allocation of parts that need to be replaced. The earlier an accurate inspection and evaluation of the remaining product life can be carried out, the less processing of products that later will be discarded will be required. In many articles, the remanufacturing process is often described as having the inspection performed after the cleaning and disassembly. This is not always efficient, however, if the product has fatal errors for example, 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 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 properties that are preferable for remanufacturing are those that facilitate the generic remanufacturing process steps shown in figure 3 above. In the next paragraphs, product properties that are essential for some of these process steps (inspection, cleaning and disassembly) are described. In this paper, the four other steps are purposely omitted to avoid repetition (c.f. [12] for further product property descriptions).

3.1 Inspection

The first step in the generic remanufacturing process is product investigation, which identifies what errors the products have and which parts need to be replaced. Often, there is a failure report attached to the product indicating the reason why the product ended up at the remanufacturing plant. For an efficient remanufacturing operation, it is crucial that the products are designed so that accurate inspections can be made at an early stage [23]. In order to determine which of the product parts have failed, the product must be easy to inspect. This means that testing points should be marked and easily accessed. Also, manuals for testing should be present at the testing area in the remanufacturing plant. The product must be safe to test and thus not include hazardous materials. Beitz [24] states that the condition of a product's parts must be easy to determine in order to know if it is useful to reuse or not. This is also the opinion of Hundal [25], who further suggests that data for materials, load limits, tolerances and adjustments etc. should be available. This, however, is not always possible because currently the majority of remanufacturing is not performed by the Original Equipment Manufacturers (OEMs), but rather by third party companies who sometimes are in direct competition with the OEM. Many third party remanufacturers, therefore, have become skilled in reverse engineering in order to determine product specifications and characteristics. In order to conduct the inspection, it is preferable to have the product parts standardized [24]. The preferable product properties for this step were summarized as:

- Ease of Identification
- Ease of Verification
- Ease of Access

3.2 Cleaning

The cleaning step also usually takes place early in the generic remanufacturing process, as the products must be cleaned in order to proceed in the remanufacturing process and proceed back to the market. This process is both product type and user dependent. For example, if a user cleans the product on a regular basis, it will be easier to clean it at the remanufacturing facility. In some remanufacturing cases, this is the most time-consuming phase in the remanufacturing process, as in the case of remanufacturing household appliances at Electrolux (see further description in the next section). It has been estimated that in remanufacturing, 90 percent of the parts must undergo cleaning [26]. In this step it is important that all areas to be cleaned are easily accessible. Preferably, products should be designed in a manner that will prevent dirt from attaching in the first place. This can be achieved by avoiding sharp edges and thresholds that could attract dirt. According to Hundal [25], the parts to be cleaned should be easily accessible and their markings should withstand cleaning. Furthermore, the surfaces to be cleaned should be smooth and wear resistant [25]. The material of the product parts that are to be cleaned must also withstand the cleaning liquids and/or equipment that are used in order to remove the dirt. The preferable product properties are summarized as follows:

- Ease of Access
- Wear Resistance

3.3 Disassembly

The third step in the generic remanufacturing process is that of product disassembly. In this step, parts, modules and components are separated from the product in order to remove malfunctioning parts. In the area of design for disassembly, research has identified several product design properties. The product parts should be, according to Johansson [27], easy to identify, handle, access and separate; if these main four properties are facilitated, then the product is designed to facilitate disassembly. The product should have standardized constructions and joints, gripping points and breaking points that are easily accessed [28]. In addition, Brennan et al. [29] highlight that the product parts should be easy to separate and handle, while Fiksel [30] adds that the components should be easily accessed and simplified to facilitate the disassembly. Product parts and joints should be designed in a manner that they will not break during disassembly, since they are to be reused at least one time. The following product properties were identified as preferable:

- Ease of Identification
- Ease of Access
- Ease of Handling
- Ease of Separation
- Wear Resistance

Additional information regarding product characteristics facilitating remanufacturing can be found in [12, 19, 21, 24, 31, 32, 33 and 34].

3.4 Improving Remanufacturability - Product Case Study

Before concluding which product properties were most preferable, two products were analyzed from a remanufacturing perspective. In this product case study, two household appliances, a washing machine (Zanussi, FL-12) and a combined freezer and refrigerator (Electro Helios, KF-3517), were analyzed from a remanufacturing perspective. The products are still in production at the Swedish manufacturer Electrolux AB. These products are two of the many household appliances currently being remanufactured at the company’s remanufacturing facility in Motala, Sweden. Design changes were suggested to facilitate the remanufacturing of the two products. This case study covered both the higher-level structures of the product as well as the lower-level details concerning joining methods and part shaping.

The two products were thoroughly examined, disassembled and reassembled many times in order to understand which design changes were needed. The working environment for disassembly and reassembly was similar to the one used by Electrolux at its remanufacturing facility, using the same tools etc. Moreover, the remanufacturing personnel were interviewed in order to understand which design changes were needed to facilitate their work. This product case study identified some useful design changes, with the following major changes suggested:

- **Different structures of the overall product design**. In the washing machine, there were several possibilities for changing the product structure in order to facilitate part disassembly.
- **Standardization of joining methods**. For example, the washing machine had many different types of screws, which could be standardized into a single type to achieve a lower number of parts and to eliminate the risk of selecting the wrong screw during reassembly.
- **Elimination or redesigning of product parts**, such as parts that interfere with the disassembly of parts. There was, for example, a steel bar in the washing machine, which interfered with the disassembly of several parts e.g. the control unit.
- **Reshaping the interior surfaces**, such as making the surfaces easier to clean. This is, for example, important for the design of the shelf tracks in the freezer/refrigerator.
- **Simplifying the electronic boxes controlling the appliances**. For instance, cable sockets can be used in place of loose cables. This will make the printed circuit board easier to change and service.

This product case study, which is further described in [35], concludes that many design changes on these two products could be made in order to facilitate remanufacturing. It is, of course, also important to consider economic aspects when redesigning for remanufacturing. The changes in design can be both major and minor, although the product's function must be the same, as has been described in these two product cases [35]. Some of the changes are easy to perform, such as changing joining type, while others require more effort, such as the changing of the product structure by alternating which parts stabilize the product. The key observations in these two product cases are design modifications, which concern the product's ease of accessibility, cleaning, disassembly and part handling. Designing for remanufacturing also makes the products easier to repair and to service, since higher accessibility is gained.

3.5 The RemPro Matrix

All the product properties from the steps in the generic remanufacturing process (Figure 4) can be condensed into the following matrix of remanufacturing product properties - the Remanufacturing Property Matrix (RemPro).

<Insert Figure 4 here>

The RemPro-matrix above, which shows which product properties are relevant for the different steps in the remanufacturing process, should be used as a design tool. Using this matrix, the designer can easily see what properties are needed for the different steps; depending on which product is being designed, any step can be of particular interest and therefore emphasized. Theoretical studies and the case studies at Electrolux have resulted in the identification of these product properties. The properties stated above in the RemPro-matrix provide the answer to the third research task stated in the introduction.

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 for remanufacturing, so the cleaning and repairing focus does not make any other remanufacturing step 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 disassembly, cleaning or reassembly will not be a factor [36]. This means that much effort can be made in product design without getting the expected benefits. As Shu and Flowers [36] 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 properties to consider when designing a product for remanufacturing. The circumstances, e.g. product type, volume, remanufacturing system etc. must not be forgotten, since they are important factors to consider when setting the remanufacturing sequence and determining which properties to prioritize.

4 Remanufacturing Process Analyses

4.1 Electrolux AB

Electrolux AB began to remanufacture household appliances in a facility in Motala, Sweden in 1998. The driving force for remanufacture at the company was mainly of environmental reasons. Since profit was uncertain from the start, it was decided to put the remanufacturing process in a seldom-used warehouse near a manufacturing plant for stoves. The equipment for the process consists of old machines that are no longer useful in ordinary manufacturing. The remanufacturing facility in Motala is mostly manual, except for some tools for testing and a computer system. The remanufacturing process is at present showing profit, and contributes to the company’s environmental image.

Most of the products that arrive at Motala are newly manufactured with failures covered by warranties, and which the 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. This analysis focuses on the products that originate from the service centers. The variety of incoming product types is shown in figure 5 below.

<Insert Figure 5 here>

When it is not possible to repair a product on site, it is delivered to Motala, via the service centers, by trucks. Upon arrival, the products are unwrapped and registered in a computer system. At this point, a decision is made whether the products are to be remanufactured or used for spare parts. The products that undergo remanufacturing are tested to find out what type of damage they have received. After testing, the products proceed either to repair or to the product spare part storage. Depending on type of product and error, the time needed for repair varies from short to long (5-30 minutes). If spare parts are needed, they can either be taken from the products at the spare part storage or ordered to the facility; this means that the products may wait for several days or even a few weeks for the right spare parts to arrive. When the products are repaired, they are cleaned and high-voltage tested. Finally, the products are wrapped in plastic and put into storage, ready for transport to retailers for resale. The Electrolux remanufacturing process is illustrated in Figure 6 below.

<Insert Figure 6 here>

4.1.1 Analyzing the Electrolux remanufacturing process

Technical aspects

The technical analysis started with an overview of the entire system and continued on remanufacturing process step level. Since there were no well-known strategies for evaluating remanufacturing processes, methods for evaluation of ordinary manufacturing processes were used. This analysis focuses on the following aspects in the process: working environments, the remanufacturing of products, work stations, transports and layout of work areas and storage. These aspects were analyzed in order to improve the process organization and to plan and make the process methods easier to work with. The following four improvements in the overall factory were suggested:

1. There should be a computer system for products that are not repaired immediately, since there are no spare parts to reassemble in the product at that moment. These products are stored in the remanufacturing plant, and if the responsible repairman gets sick, no one knows which spare part is needed and what error the product has. If the product is registered in a computer system, however, any repairman can see what the error is and what new parts are needed.

2. To improve the disassembly of spare parts, which will be used in other products, and their storage, a manual should be utilized describing which parts to disassemble. Preferably, there should be a worker who is responsible for the spare part storage. On the other hand, this solution might be too expensive, since it is more suitable for higher remanufacturing volumes.

3. The repairmen should have continuous education about how to remanufacture new products in order to obtain higher yields for remanufactured products. It could also be useful for the repairmen to learn how to perform remanufacturing steps other than those they are experts at, enabling them to add flexibility to the remanufacturing process.

4. Installing a gas station to fill up new cooling liquids in the refrigerators would increase the yield of the remanufacturing. At present, when there is no gas station in the facility, 2/3 of the refrigerators are not remanufactured, since there is no station for gas filling at the facility.

Looking at a more detailed remanufacturing step level, the following improvements were found and suggested:

Collection: the service personnel at the service centers should have the authority and knowledge to scrap the products which are obviously not worth remanufacturing in order to avoid long transports to Motala; today, all products that have failed to be repaired on site are transported to Motala. This action will reduce the number of transports and increase the yield of the remanufacturing process.

Repairing: A worktable that is adjustable in height should be installed to ease the repairing of washing machines. Such a working table already exists for the stoves.

Testing: More test equipment should be installed in order to reduce the amount of transport of other test equipment.

Cleaning: This remanufacturing step was found to be the bottleneck of the remanufacturing process. To increase efficiency in this step, the following actions can be taken:

- Install steam cleaning.
- Train the 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.

Printing manuals: There should be manuals ready to print out from a computer. This saves storage space currently filled by today's manuals.

To conclude the technical analysis, there are some aspects for Electrolux to consider in order to make the remanufacturing process more efficient. Information about the products being remanufactured could be better documented in a computer system throughout the entire process. As suggested above, the bottleneck in the process, the cleaning step, could be made more efficient. Some of the technical improvements that are suggested in this article are at present expensive, but with higher production volume will become more economically benign. The technical improvements at the remanufacturing step level are further described in [37].

Economic aspects

The technical analysis was followed by an economic analysis to find out where the costs were derived from and to get a better view of the process. This allowed the company to know where to make changes in the process in order to achieve lower costs in the future. The economic analysis was conducted through an Activity Based Costing (ABC) method. 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 more to the their real origin. The ABC method distributes the costs on the resources that actually use the resource, c.f. [10 and 38]. 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. 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 are not accounted for. In this project, ABC seemed useful since there were no excessive activities that could complicate the calculations.

Economic calculations were made for each product type (see Figure 5) using the ABC method. They showed almost the same results for all types, i.e. the costs were shared likewise between the product types. There were some exceptions, however, such as the cleaning of stoves, which had a slightly larger share (16 percent) of the total remanufacturing costs than the cleaning share of other products (~10 percent). Moreover, the microwave ovens were, in general, shown to be cheaper to repair and clean than the other product types. The following chart (Figure 7) illustrates the cost distribution for all remanufactured products for the entire remanufacturing process.

<Insert Figure 7 here>

Since there are three storage areas in the facility where the products are held in storage, sometimes for days, it is not surprising that it has the largest share of the remanufacturing costs (24 percent), as illustrated in figure 7 above. Included in the costs for storage is the storage of incoming products, outgoing products and spare parts. Since this share is large, one might consider ordering new spare parts rather than having the products stored. This decision is dependent on the amount of space that is available for storage as well as the costs for renting this space. Administration also has a large cost share (13 percent) and consists mainly of salaries and the computer system used to track the products. This share will most probably decrease as volumes and yields in the remanufacturing plant increase. Cleaning and repairing the products have the two largest shares of costs (both 11 percent) besides storage in the actual remanufacturing process. Also, transports stands for a large part (11 percent) of the costs, but these are not considered as being included in the remanufacturing process. Cleaning was also a remanufacturing step that needed to be improved, according to the technical analysis. Making any of the suggested changes, in fact, could make this step more efficient and reduce costs.

To conclude, the economic and technical analyses of the remanufacturing facility in Motala showed that there are several actions that could be taken to make the process more efficient. The flow of material in the facility could be more organized and the bottleneck in the process, cleaning, could be enhanced by assigning more personnel to work at the step or by introducing steam cleaning. At present, the remanufacturing in Motala is profitable, although the volumes are quite low (5,500 products/year in 2001). This is partly due to the fact that old equipment and areas with low rent are used. One way of making the remanufacturing process more profitable is through cost reduction efforts. The economic calculation with the ABC method showed that a major part of the costs are derived from product storage. This is due to three different storage areas included in the facility: incoming products, spare parts and outgoing products. Administration was also one of the most expensive activities in the facility, but both of these activities will have smaller cost shares as volume increases. In the remanufacturing process, the steps of product cleaning and repairing had high cost shares.

Both the economic and technical analyses pointed out that the cleaning phase was a critical factor in the high share of costs and ineffectiveness. If the remanufacturing process were to be improved, more effort should be put into this step of the remanufacturing process. This could be achieved by both improving the process and the products being remanufactured. If the products are easier to clean, the cleaning step will not be the bottleneck in the process as it is today. The product case study provides an example of how to design a refrigerator for cleaning. The shelf tracks inside the refrigerator could be designed with a small radius, making it easier to clean. In the literature, the product properties found to enhance cleaning were ease of access and resistance to wear. That means that it should be easy to access all parts that need to be cleaned, and that the product should withstand the cleaning liquids required for cleaning.

As mentioned before, the research for this paper focuses on economic and technical aspects. The environmental aspects of this facility have been analyzed both by Electrolux and Linköping University. Both analyses show that remanufacturing is an economic and environmentally preferable option. The analysis conducted at the university is summarized in [8].

4.2 Automotive Part Rebuilders

This finding at Electrolux is directly supported by results from a survey among automotive parts rebuilders presented in [11]. Figure 8 shows the answers to the question of *"Which remanufacturing operations are most costly?"*. The responses clearly indicate that part replacement is by far the most expensive operation, but the second most costly operation is cleaning. Remanufacturers in other studies have also pointed out that cleaning is an expensive process step from an environmental point of view. This is due to the removal of old paint coating, oil, grease or other debris from cores, which always results in some amount of waste that is hazardous if discharged untreated. A lot of cleaning operations use volatile organic compounds (e.g. xylene) that contribute to air pollution and put workers at risk. If sand blasting is used for cleaning, particulates enter the immediate work environment and worker health may be at risk. Water based cleaning typically require solvents that have to removed from the water before it can be discharged again. Given these issues, many remanufacturers are subject to environmental permit requirements from both the federal Environmental Protection Agency (EPA) and local State environmental protection divisions and agencies in the USA. Due to these environmental compliance pressures (and their associated financial costs in terms of equipment and overhead), many remanufacturers are actively pursuing pollution prevention in their operations. For example, Caterpillar has significantly improved its cleaning operations in order to reduce water use and effluent emissions in its Corinth Mississippi remanufacturing facility [39]. However, indirect environmental effects also occur from cleaning. The use of large ovens to bake off dirt and oil debris in automotive remanufacturing avoids the use of restricted solvents, but increases energy consumption and subsequently CO_2 emissions when fossil fuel burning powerplants are used. According to the EPA Toxic Release Inventory data[IV], coal burning power plants are the most polluting facilities in the United States with respect to air releases in the USA – not even including CO_2 emissions. The same data shows that the largest solid waste releases stem from mining operations. Given this, it is not surprising that cleaning is a critical issue in remanufacturing and deserves more attention in academia. It is interesting to observe that disassembly is not really an issue, according to practicing remanufacturers.

<Insert Figure 8 here>

5 Conclusions

Functional sale is a business strategy that has increased in popularity in recent years. The concept, however, while long recognized, has only recently begun to be seen as an environmental benefit. Specifically, there is less strain put on the environment from mining operations. Furthermore, retaining physical form can result in net energy savings compared to casting or injection moulding a new shape (e.g. motor housings). In order to enable the physical product to provide many services during its functional lifetime, it should to be designed for both durability and remanufacture/upgrade. The rationale here is that if the products last longer through design for remanufacturing, less material can be used to meet customer needs.

Remanufactured products that are sold through functional sales provide the remanufacturing company with better control of the products arriving at the remanufacturing facility. Moreover, the computer system controlling the functional sales could be synchronized with the system used in the remanufacturing to ease the administration at the facility. By selling products as functions, the storage of products being remanufactured is moved from the remanufacturing facility to the customer. These two opportunities gained by using functional sales in connection with remanufacturing are ways of lowering the remanufacturing costs described in the case studies. Furthermore, having knowledge of when and how many products are entering the remanufacturing process (through functional sales) makes the remanufacturing process easier to plan and manage. The logistics and handling of the incoming products are often a problem in the remanufacturing business, which through functional sales could be partly solved. The Swedish forklift manufacturer BT Industries has several potential

[IV] See www.epa.gov/triexplorer/

revenues to earn by implementing the combination of functional sales and remanufacturing more thoroughly. In order to make its business more beneficial, the product information should be accessible for the remanufacturing personnel and the products should be adapted for the remanufacturing process, which should also be upgraded for the larger volumes of forklifts projected for remanufacture in the future.

Currently, products are often not designed for remanufacture. It has been shown, however, that there are economical benefits to be gained by designing products for remanufacturing, c.f. [9]. The case study of the two household appliances described in this paper has shown that there is much to consider when adapting products for remanufacture. A way of designing products for remanufacturing is to let the parts that are worn out quickly in the product, or that require frequent upgrading, to be placed in the product structure in such a manner that they are easy to replace with new parts.

Combining the results from the remanufacturing process studies, *cleaning* and *repairing* were identified as critical remanufacturing steps from both the technical and the economic perspectives. To facilitate these steps, one can read from the RemPro-matrix (Figure 4) that designers should focus on designing products with the following properties: *ease of access*, *ease of handling*, *ease of separation* and *wear resistance*. Although this study presents the case of household appliances and automotive parts, the distribution of costs may differ depending on which product is being remanufactured.

6 Future Research

Since there are few studies looking at functional sales in combination with remanufacturing, more research is needed to determine to what extent these concepts can work in concert. Furthermore, additional remanufacturing facilities, with different kinds of products and remanufacturing process choices, need to be studied. Does remanufacture work better for a special type of product? Finally, environmental calculations spanning the entire product life cycle, including functional sales and remanufacturing are also needed to ensure to what extent these concepts are environmentally benign.

7 Acknowledgements

The authors would like to thank Kurt-Erik Hellström and Alf Hedin at Electrolux AB for being helpful and supporting our empirical studies. Furthermore, we wish to send regards to the master students who helped to collect empirical data at Electrolux AB. We would also like to thank the Programme for Production Engineering Education and Research (PROPER) and the Swedish EPA, without whose financial support this research would not have been possible.

8 References

[1] World Commission on Environment and Development (WCED), pp 43, 1987.

[2] Gungor A. and Gupta S. Issues in environmentally conscious manufacturing and product recovery: a survey, Computers and Industrial Engineering 36 (1999) pp 811-853.

[3] McIntosh, M. and Bras, B. A. Product, process, and organizational design for remanufacture - an overview of research. Robotics and Computer Integrated Manufacturing - Special Issue on Remanufacturing **15**: 167-178, 1999.

[4] Guide Jr. V.D.R. Production planning and control for remanufacturing: industry practise and research needs, Journal of Operations Management 18 (2000), pp 467-483.

[5] Ryding S., Ekvall T., Karlsson L., Karlsson R., Nevén C-O., Tillman A-M., Steen B. and Westerlund G. *Miljöanpassad produktutveckling*, Industriförbundet, Stockholm, Sweden, ISBN 91-7548-410-2, 1996, (in Swedish).

[6] Graedel T.E. and Allenby B.R. *Design for Environment* AT&T Published by Prentice Hall, USA, ISBN 0-13-531682-0, 1996.

[7] Steinhilper R. *Remanufacturing - The Ultimate Form of Recycling*, Fraunhofer IRB Verlag, Stuttgart, ISBN 3-8167-5216-0, 1998.

[8] Sundin E. and Tyskeng S. Inverse Manufacturing at Electrolux or Recycling at Local Facilities? -A Comparison from Environmental and Economic Perspectives, *Proceedings to EcoDesign –03*, Japan, Tokyo, 2003.

[9] Kerr W. and Ryan C. Eco-efficiency gains from remanufacturing - A case study of photocopier remanufacturing at Fuji Xerox Australia, Journal of Cleaner Production no.9, pp 75-81, 2001.

[10] Emblemsvåg, J. and B. A. Bras. Activity-Based Cost and Environmental Management - A Different Approach to the ISO 14000 Compliance. Boston/Dordrecht/London, Kluwer Academic Publishers, 2000.

[11] Hammond, R., Amezquita, T. and Bras, B. Issues in Automotive Parts Remanufacturing Industry: Discussion of Results from Surveys Performed Among Remanufacturers. Journal of Engineering Design and Automation, Special Issue on Environmentally Conscious Design and Manufacturing **4**(1): 27-46, 1998.

[12] Sundin E. Design for Remanufacturing from a Remanufacturing Process Perspective, Linköping Studies in Science and Technology, Licentiate Thesis No. 944, Department of Mechanical Engineering, Linköpings Universitet, 581 83 Linköping, Sweden, ISBN 91-7373-336-9, 2002.

[13] Lindahl M. and Ölundh G. The Meaning of Service selling, Proceedings to Life Cycle Engineering (LCE-2001), Varna, Bulgaria, 18- 29 June, 2001, pp 211-220.

[14] Lifset R. Moving from product to Services, Journal of Industrial Ecology Volume 4, No.1, MIT Press, Five Cambridge Center, Cambridge, MA, USA, 2000, pp 1-2.

[15] Mont O. Product-Service Systems - Final Report, International Institute of Industrial Environmental Economics, Lund University, AFR-REPORT 288, Swedish EPA, 106 48 Stockholm, Sweden. ISSN 1102-6944, 2000.

[16] Kimura F. Inverse Manufacturing: From Products to Services, The First International Conference on Managing Enterprises - Stakeholders, Engineering, Logistics and Achievements (ME-SELA ´97) July 22-24 1997, Loughborough University, The United Kingdom.

[17] BT Brochure: Don't buy Trucks. BT Products, Mjölby, Sweden, 2001., BT Brochure: Handling innovation, BT Products, Mjölby, Sweden, 2001 and BT Homepage, 2001, www.bt-industries.com, accessed 2001-10-09.

[18] Lund R. and Denny W. Opportunities and implications of extending product life. Symposium on Product Durability and Life, Gaithersburg, MD, pp 1-11, 1977.

[19] Lund, R. T. Remanufacturing. Technology Review, Vol. 87, pp. 18-23, 1984.

[20] Lund R. and Skeels F. Guidelines for an original equipment manufacturer starting a remanufacturing operation, Government Report, DOE/CS/40192, CPA-83-8. Cambridge, MA: Massachusetts Institute of Technology, Center for Policy Alternatives, 1983.

[21] Amezquita, T., R. Hammond and B. Bras. Characterizing the Remanufacturability of Engineering Systems. 1995 ASME Advances in Design Automation Conference, DE-Vol. 82, Boston, Massachusetts, ASME, pp. 271-278.

[22] Ijomah W.L., Bennet J.P. and Pearce J. Remanufacturing: Evidence of Environmentally Concious Business Practice in the UK. Proceedings to International Symposium on Electronics and the Environment (IEEE), Danvers, USA, 11-13 May 1999, pp 192-196.

[23] Jacobsson N. Emerging Product Strategies: Selling services of remanufactured products, Licenciate thesis at the International Institute for Industrial Environmental Economics (IIIEE), Lund University, Sweden, 2000.

[24] Beitz W. Designing for ease of recycling - general approach and industrial application. Proceedings to International Conference on Engineering Design (ICED), The Hague, The Netherlands, 17-19 August 1993, pp 731-738.

[25] Hundal M.S. DFE: Current status and challenges for the future, DE-Vol.67, Design for Manufacturability, ASME-1994, pp 89-98.

[26] Steinhilper R. Produktrecycling - Praxis und Perspektiven, Proceedings to International Conference on Engineering Design (ICED), Vol.3, pp 1561-1568, Zurich, Switzerland, 1990.

[27] Johansson G. Design for disassembly - A framework, Licentiate thesis at the Division of Production System, Department of Mechanical Engineering at Linköping Universitet, AFR-report 174, 1997.

[28] Kuuva M. and Airila M. Design for Recycling, Proceedings to International Conference on Engineering Design (ICED), The Hague, The Netherlands, 17-19 August, 1993, pp 804-811.

[29] Brennan L., Gupta S. and Taleb K. Operations Planning Issues in an Assembly/Disassembly Environment. International Journal of Operations & Product Management, vol. 14, No. 9, 1994, pp. 57-67.

[30] Fiksel J. Design for Environment: creating eco-efficient products and processes. McGraw-Hill, USA, 1996. ISBN: 0-07-020972-3.

[31] Haynsworth, H. and Lyons, R. Remanufacturing by Design, The Missing Link. Production and Inventory Management, Second Quarter, pp. 25-28, 1987.

[32] OTA. Green Products by Design: Choices for a Cleaner Environment. OTA-E-541, Office of Technology Assessment, Washington D.C., 1992.

[33] Berko-Boateng, V., Azar, J., De Jong, E. and Yander, G. Asset Recycle Management – A Total Approach to Product Design for the Environment. International Symposium on Electronics and the Environment (IEEE), Arlington, Virginia, 1993, pp. 19-31.

[34] VDI 2243. Konstruieren Recyclinggerechter Technischer Produkte (Designing Technical Products for ease of Recycling), VDI-Gesellschaft Entwicklung Konstruktion Vertrieb, Germany, 1993.

[35] Sundin E. 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.

[36] Shu L.H. and Flowers W.C. Reliability Modelling in Design for Remanufacture, Journal of Mechanical Design, vol. 120, pp 620-627, 1998.

[37] Sundin E. An Economical and Technical Analysis of a Household Appliance Remanufacturing Process, Proceedings of EcoDesign 2001, Tokyo, Japan, 12-15 December 2001, pp 536-541.

[38] Cooper, R. ABC: A Need, Not an Option. Accountancy (September), 1990: 86-88.

[39] Gutowski, T. G., Murphy C. F., Allen D. T., Bauer D. J., Bras B., Piwonka T. S., Sheng P. S., Sutherland J. W., Thurston D. L. and Wolff E. E. Environmentally Benign

Manufacturing. Baltimore, MD, International Technology Research Institute, World Technology (WTEC) Division, 2001.

Figures:

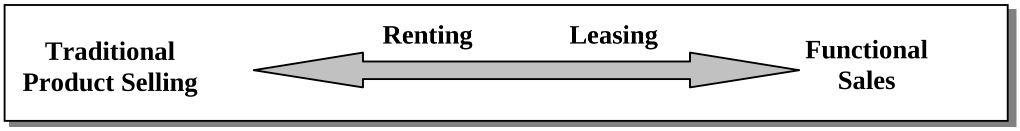

Figure 1: A scale from traditional product selling to functional sales [12].

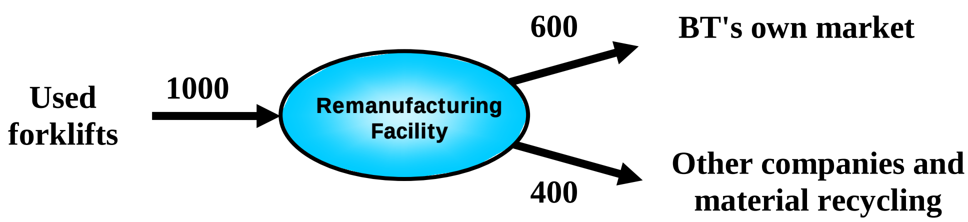

Figure 2: The flows of forklifts through the remanufacturing plant at BT Industries in Mjölby, Sweden during 2001.

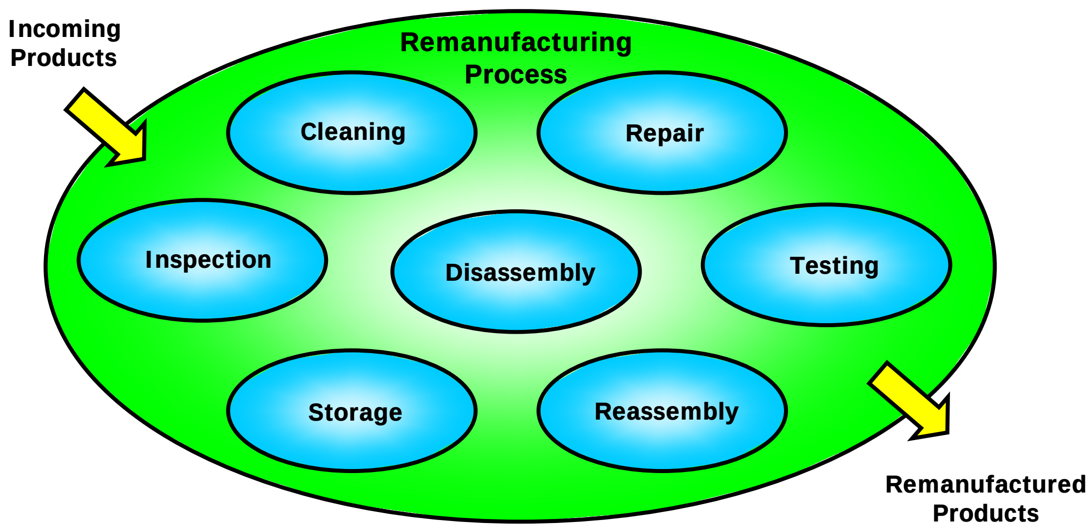

Figure 3: The steps in a generic remanufacturing process [12].

Product Property \ Remanufacturing Step	Inspection	Cleaning	Disassembly	Storage	Repair	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 4. The RemPro-matrix showing the relationship between the essential product properties and the generic remanufacturing process steps [12].

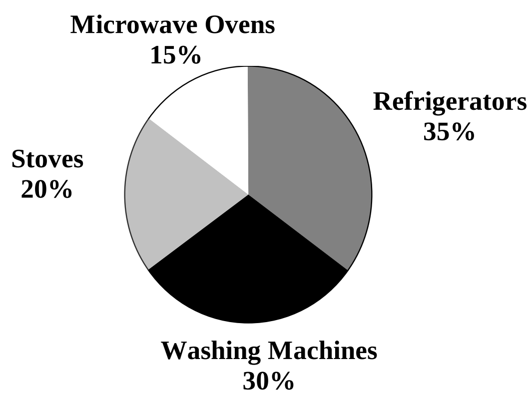

Figure 5: The mix of products for the remanufacturing facility in Motala, Sweden during 2001 [37].

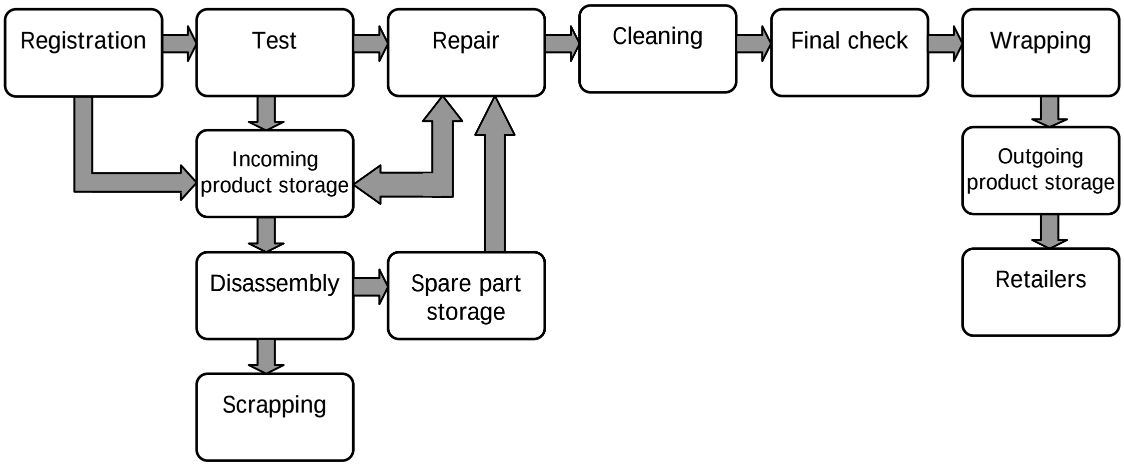

Figure 6: The remanufacturing process showing the main material flows at the Electrolux remanufacturing facility in Motala, Sweden [37].

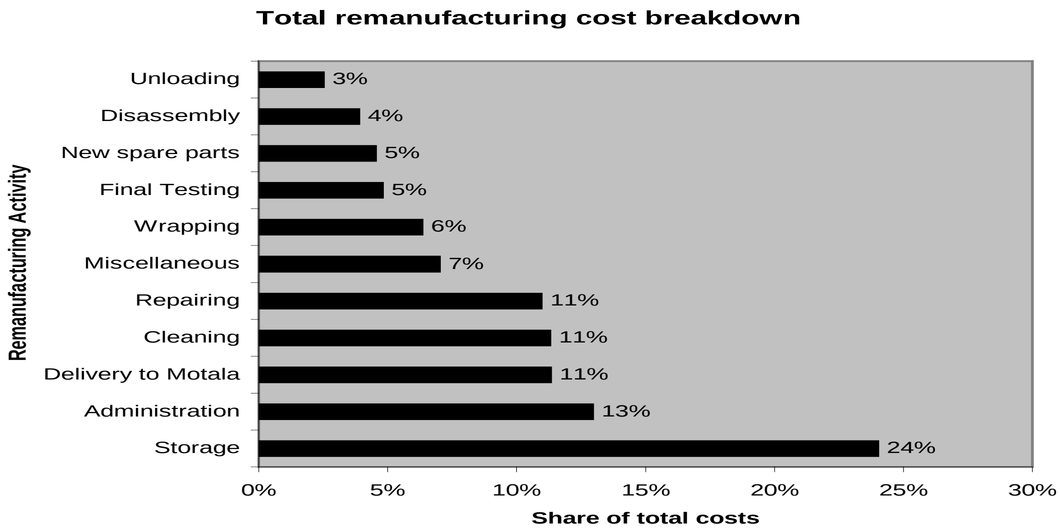

Figure 7: The total remanufacturing cost breakdown for all products being remanufactured at Electrolux's facility in Motala during 2000 [33].

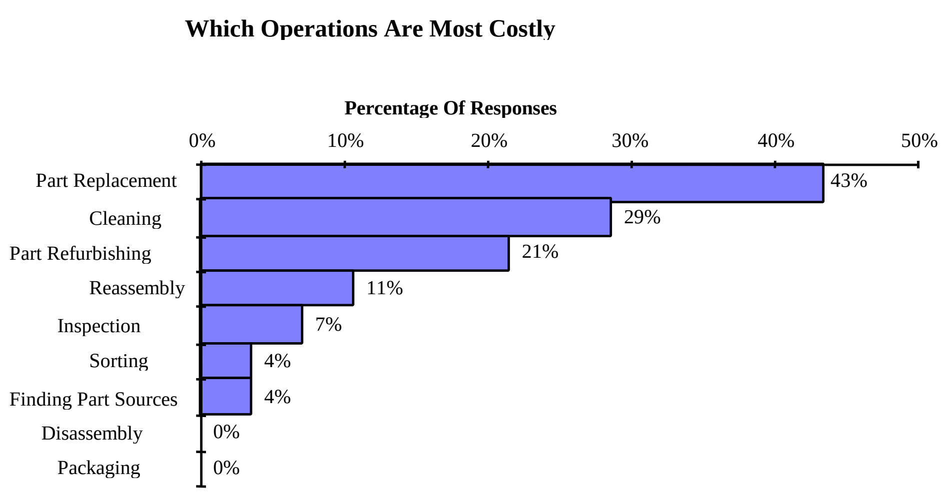

Figure 8: Most costly remanufacturing operations according to automotive parts remanufacturers [11].