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**Product Design for Product/Service Systems  
- design experiences from Swedish industry**

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Having a life-cycle perspective on products and services in the business strategy of product service systems is increasingly important as the strategy emerges and more and more companies see the benefits of controlling a larger share of the product value chain. The business approach of product/service systems puts new requirements on products in comparison to traditional selling. Since the volumes of products being sold through product/service systems are increasing, these design issues need to be considered on a larger scale. The objective of this paper is to elucidate how three Swedish manufacturers have worked with or could adapt their products for product/service systems. The three case study companies manufacture forklift trucks, soil compactors and household appliances, respectively. A key factor when developing products for product/service systems is to design the product from a life-cycle perspective, considering all the product's life-cycle phases, namely manufacturing, use, maintenance and end-of-life treatment. Several design improvements, all of which are fairly inexpensive and easy to implement, are described in the paper. Many of these improvements deal with the accessibility of parts and components during maintenance and remanufacturing operations, and several of the design improvements could reduce the need and cost for maintenance, repair and remanufacturing.

**Keywords:** PSS; engineering design; life-cycle design; remanufacturing; DFRem

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## 1. Introduction

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 be achieved, in concert with environmental benefits, by improving the ability to offer a higher degree of integrated product services instead of focusing only on physical products (Lindhahl and Ölundh 2001, Tischner et al. 2002). Furthermore, there are good economic opportunities in the aftermarket of the products, as exemplified in the automobile industry. Because of this, many manufacturing companies are changing their production philosophies from a traditional focus on the manufacturing of the physical product towards a focus on the life-cycle of the physical product. As a result, more focus is now put on the use and end-of-life phases, including maintenance and remanufacturing (Sundin et al. 2005a). Remanufacturing is a process of returning a used product to at least original equipment manufacturer (OEM) original performance specification from the customers' perspective, and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent (Ijomah 2002). It is an important aspect of environmentally conscious manufacturing and of Product/Service Systems (PSS) because it extends products' lives to reduce expenditure on new products and also limits landfill by integrating back into the production chain used components that would otherwise have entered landfill.

The phenomenon of Product/Service Systems (PSS) has become more prevalent in current consumer patterns, and its emergence is primarily market-driven. In these PSS offerings, a very strong focus is placed on how to fulfil customer needs and create customer value (Lindhahl and Ölundh 2001). Although the idea is also named in practice and literature as “functional sales“, “product service combinations”, “product-to-service”, “integrated product service offerings” and “servicizing”, the authors most often mean the same thing (Lifset 2000). This paper uses a broad definition of PSS that includes for example business aspects dealing with renting, leasing and similar concepts as long as the product is operated by the manufacturing company. An example of a PSS offering 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. PSS offerings have the potential to be environmentally benign, as they address current levels of material consumption while seeking options that may provide functions to the consumer, and without minimizing their level of welfare (Mont 2000). In the previously mentioned laundry case, since there is an economic incentive for the user, the machines could be filled more efficiently, thus decreasing the overall water and power usage. However, environmental benefits are seldom brought up as a driver for PSS; instead, most drivers are connected to customer demands (Sundin et al. 2009).

PSS offerings are also in line with what the Japanese market demands. Matsuda and Shimomura (2003) discuss how the Japanese market is saturated with physical products, and that its customers are increasingly demanding more functions and services in combination with the physical products. The business concept of PSS offerings is still emerging, and there is a lack of empirical data concerning its practical application. More data and information is needed in order to analyze how companies are approaching the concept in order to enhance its productivity. This means that, for example, the service provider could put more focus on the use and end-of-life phases for the physical products included in the product-service combinations. When the service provider has control over the physical products during the use phase, the incitement for cost reduction increases. For example, if maintenance and spare parts are included in the offering then the provider would try to reduce these costs. Hence, PSS puts more requirements on products in comparison to traditional product selling.

### ***1.1 Objective***

The objective of this paper is to elucidate how Swedish manufacturers have worked with or could adapt their physical products for product/service systems. A focus was put on exploring the adaptation for maintenance, repairs and remanufacturing since these steps were where the providers met their products during their life-cycles. The research is based on three case studies performed at three Swedish manufacturers: Toyota Material Handling Group (forklift trucks), Swepac International AB (soil compactors) and Electrolux AB (household appliances).

### **2. Methodology**

To fulfil the objective of this paper, previous research was studied along with newly collected empirical data and information. This previous research includes, for example, guidelines and design properties that have been shown to be beneficial for PSS, such as those presented by Sundin and Bras (2005). New empirical data was obtained from three Swedish manufacturers: Toyota Material Handling Group (forklift trucks), Swepac International AB (soil compactors) and Electrolux (household appliances). The products studied were selected because they were all excellent candidates for design for PSS; this was important as the ability to remanufacture has significant impact on the success of PSS. All three products were appropriate candidates for redesign for enhanced remanufacturing potential because they were mature, pervasive products, providing an ample supply of used products to remanufacture and to cannibalise for remanufacturing. Additionally, they were not fashion-affected products, and were not placed in a prominent position in the home. Thus, age, make and model are far less important than their functionality. Research shows that remanufacturing thrives under such circumstances.

Three redesign case studies, one for each company, were performed. Each company was visited several times in order to find out how they worked with design and PSS issues. By doing so, a good understanding of how the products were used in the PSS was achieved. Information was obtained through semi-structured interviews of personnel from each company, e.g. managers, designers and operators. The studies analyzed, through observations and interviews, how the companies maintained and remanufactured their products. Personnel from the companies' maintenance and remanufacturing departments were interviewed to determine their views about their products' designs. Also, employees at both the management and operator levels were interviewed, and questionnaires were used to gather information about their views on how their product designs could be improved to better fit PSS. As part of each case study, each company's product was studied in a laboratory at Linköping University. Researchers and Master level students together analyzed each product, for example, by disassembling and assembling it many times in order to uncover design improvements. The origin of the redesign proposals came from the researchers and students when disassembling/reassembling in the university environment. Furthermore, in order to verify the results from each case study, additional mechanical engineers and designers were interviewed to determine the design department's views about the proposed design improvements.

### **3. Product/Service Systems**

The phenomenon of PSS has become more prevalent in current consumer patterns, and its emergence is primarily market-driven. The importance of services gets larger as the economy of our society matures. Service activities are provided as the source of core value in the tertiary industry. In addition, the secondary industry has recently become increasingly interested in services (e.g. PMHAPT 2002, Oliva and Kallenberg 2003). The importance of services is also recognized in the marketing field (Vargo and Lusch 2004). As a

result, new concepts such as Product/Service System (PSS) (Goedkoop et al. 1999, Morelli 2003, McAlloone and Andreasen 2004, Mont 2004, Tukker and Tischner 2006, Aurich et al. 2006), Functional Sales (Lindahl and Ölundh 2001, Sundin and Bras 2005), Functional Products (Alonso-Rasgado and Thompson 2006, Alonso-Rasgado et al. 2004), Integrated Product Service Engineering (IPSE) (Sundin et al. 2006), and Service/Product Engineering (SPE), formerly called Service Engineering (Sakao and Shimomura 2007), have been developed. What these concepts have in common is the incorporation of a service into the design space, which has been traditionally dominated by physical products in manufacturing industries. In PSS, a very strong focus is placed on how to fulfill customer needs and create customer value (Lindahl and Ölundh 2001); thus, the main focus is not on producing new products. Furthermore, Sakao et al. (2008) provide a good overview of recent research directions in the PSS area.

Today, value is added to products in a variety of ways, including technological improvements and non-material 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 customers' demands. According to Mont (2004), this means a change from mass production to mass customization. The issues of combining the development of mass-customized products used in PSS are further described in Sundin et al. (2007). Kimura (1997) states that a paradigm shift is needed to change from traditional product selling to more service-oriented product sales. In addition, the traditional boundary between manufacturing and services is becoming increasingly blurred (Mont 2004). Within PSS, 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. In the cases of renting, leasing and PSS offerings, the product is not sold, and a contract is written between user and provider; however, this contract is more advanced for the PSS offerings concept. Leasing is a contract form that often is used for financial reasons, as products are often sold to the customers who leased them when the contract has run out. Tischner et al. (2002) have studied the links between PSS and traditional products and services. The general image of a PSS can, as shown in Figure 1, be broken down to three main categories: product-, use- and result-oriented PSS.

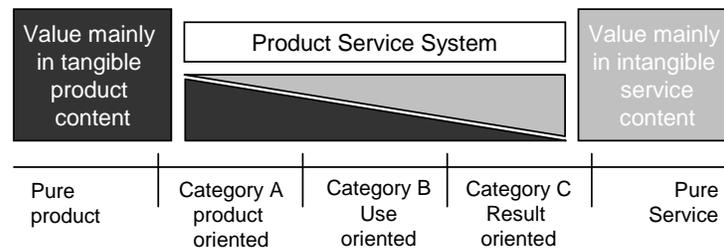


Figure 1. Placing product/service systems in a perspective to products and services (Tischner et al. 2002).

**Category A: Product-oriented Services** – Product is owned by the user/consumer.

- *Service Integration* - a new service is added to an existing product, often initiated through availability of new technology such as a modem for a computer.
- *Product Extension Service* - the value of a product is increased through an additional service, for example, upgrading, repair and guarantees.
- *Vertical Integration* - modified delivering strategies to supply products to customers, retailers and/or customers, who become directly involved in the process of production; for example, production on demand.

**Category B: Use-oriented Services** – Product is owned by the service provider, who sells functions instead of products by means of modified distribution and payment systems; for example, sharing, pooling and leasing.

**Category C: Result-oriented Services** – In a product-substituting service, products are substituted by new services, often driven by new technologies; for example, virtual answering machines instead of the machine at home, pest control services instead of pesticides, and facility management, where the supplier provides incentives for the customer to consume more efficiently and optimizes a system, for example by using modified payment systems such as contracting.

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 (Lindahl and Ölundh 2001). 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 can be facilitated by today's information technology. Monitoring the product for PSS 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 life-cycle and what needs to be improved. This knowledge allows the manufacturer to improve its products accordingly; for example, it could help to reduce the need for service throughout the use phase, discover latent design errors more quickly and obtain better knowledge of how the product is used. Having an ownership-based relation to the customer, i.e. the provider owning the product during use, have been found to be one of the most preferable relationships in achieving a successful remanufacturing business (Östlin et al. 2008).

#### **4. The remanufacturing concept and significance**

Remanufacturing is a process of returning a used product to at least original equipment manufacturer (OEM) original performance specification from the customers' perspective, and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent (Ijomah 2002). The practice is being regarded as a more sustainable mode of manufacturing, as it harms the environment less than conventional manufacturing and is profitable (Lund 1996, Hormozi 1996, McCaskey 1994). This is important in PSS, because it can help limit operating costs. It is suggested that up to 85 percent by weight of remanufactured products may be obtained from used components, and that such products have comparable quality to equivalent new products - but require 50 percent to 80 percent less energy to produce. Remanufacturing can also provide 20 to 80 percent production cost savings in comparison to conventional manufacturing.

Remanufacturing differs from related product recovery processes of repair and reconditioning in four major ways. The most important of these is that remanufactured products have warranties equivalent to those of new alternatives, while repaired and reconditioned products have inferior guarantees (Ijomah 2002). Also, remanufacturing typically involves greater work content than the other two processes, and as a result its products tend to have superior quality and performance (Ijomah 2002). Additionally, remanufactured products lose their identity, but repaired and reconditioned products retain it; the reason for this is that in remanufacturing, all product components are assessed, and those that cannot be brought back at least to original performance specification are replaced with new ones. Thus, a remanufactured product would comprise both newly manufactured and remanufactured components. Finally, remanufacturing may involve upgrade of a used product beyond its original specification, something which does not occur in repair and

reconditioning. Remanufacturing also differs from recycling, which describes the series of activities by which discarded materials are collected, sorted, processed and used to produce new products. Remanufacturing is preferable to recycling because it adds value to waste products by returning them to working order, whereas recycling simply reduces the used product to the value of its raw material. Figure 2 shows the processes of remanufacturing, reconditioning and repair on axes based on the typical warranty and performance of products as well as the work content normally required.

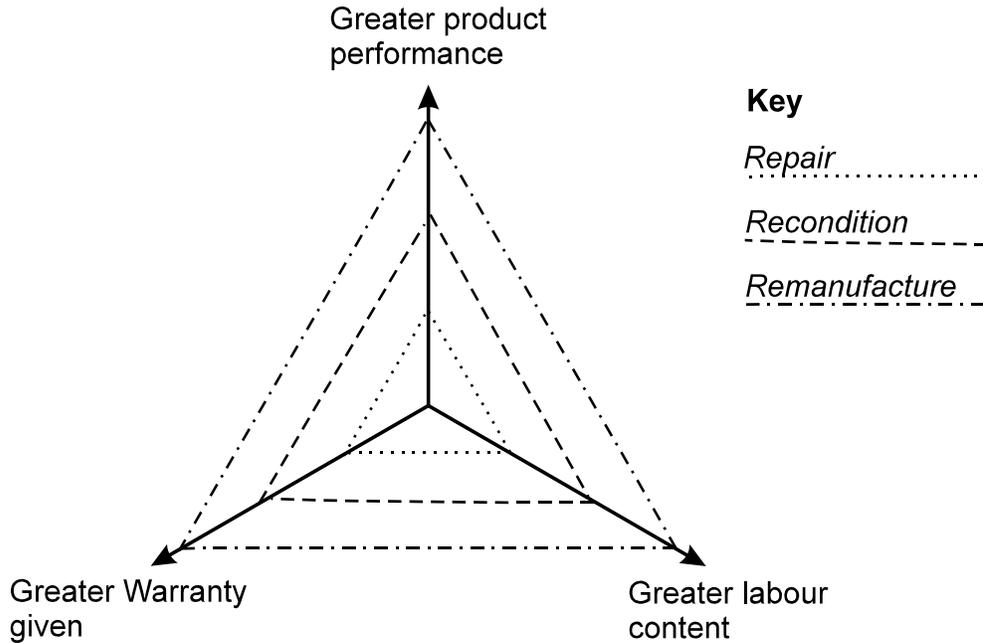


Figure 2. A hierarchy of secondary market production processes (Ijomah 2002).

Remanufacturing typically begins with the arrival of a used product (the core) at the remanufacturer, where it passes through a series of industrial stages including disassembly, cleaning, part remanufacture and replacement of unremanufacturable parts, reassembly and testing to produce the remanufactured product. Sundin (2002) states that the order in which these activities, shown in Figure 3 and described in Ijomah et al. (1999), are undertaken may differ between different product types. Andrue (1995) lists the characteristics of remanufacturable products:

- (a) The product has a core that can be the basis of the restored product
- (b) The product is one that fails functionally rather than by dissolution or dissipation
- (c) The core is capable of being disassembled and of being restored to current specification
- (d) The recoverable value added in the core is high relative to both its market value and its original cost
- (e) The product is one that is factory built rather than field assembled
- (f) A continuous supply of such cores is available
- (g) The product technology is stable
- (h) The process technology is stable

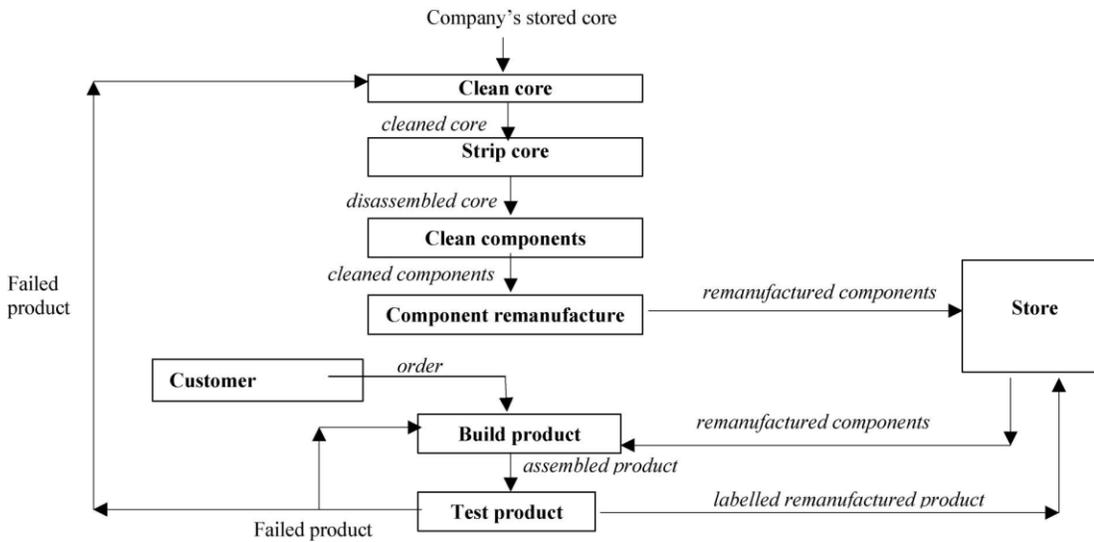


Figure 3. A generic remanufacturing flow chart.

## 5. Design for Product/Service Systems

When designing for PSS offerings, a broad perspective over the product life-cycle is needed. This includes, for example, the stages of manufacturing, maintenance, logistics and remanufacturing. In a survey conducted at Swedish, Japanese, Italian and German manufacturers using the PSS offering approach, the companies were found to seldom adapt their products for PSS offerings (Sundin et al. 2009). Earlier research by e.g. Kerr and Ryan (2001) and Sundin and Bras (2005) have also shown that there are several benefits to earn by adapting PSS offerings for remanufacturing. The significance of design-for-remanufacturing (DFRem) - and indeed of any other elements of design-for-service - is that design is the stage that has the strongest influence on environmental impact, and which sets the product's capabilities.

Key remanufacturing problems include the poor remanufacturing potential of many products, as design has typically focused on functionality and cost at the expense of environmental issues. Moreover, designers may lack remanufacturing knowledge because there is a paucity of remanufacturing knowledge and research (Guide 1999, Ferrer 2001, Ijomah 2002). Research indicates that design-for-recycling has received more attention among design and manufacturing engineers than design-for-remanufacturing (Ishii 1998a), even though remanufacturing may provide greater environmental and financial benefits than recycling. For example, many designers are reluctant to use recycled materials because of uncertain quality or supply standards (Chick and Micklethwaite 2002). Furthermore, additional energy is required to reform recycled materials into manufactured products because the energy embodied in the materials and purchased parts assembled in the initial manufacture of the product is lost during the recycling process (Jacobs 1991). Research by Lund (1984) has shown that when the total energy used in initially producing a product is summed up and compared to the energy required to remanufacture the product, the ratios are in the order of 4:1 and 5:1. This is because energy is used in every stage of manufacture, from ore smelting, assembly, and refining, through to test.

When adapting products for any of these life-cycle phases, for example remanufacturing, all of the operation steps should be considered. For instance, if one step such as reassembly is very difficult to perform on a product, it does not matter, in respect to remanufacturing, how much effort has been put into adapting the product for disassembly. One should remember that the essential goal in remanufacturing is part reuse. Thus, if a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly will be of no consequence in the case of remanufacturing (Shu and Flowers 1988). This means that much effort can be made in product design without obtaining any expected benefits.

The need to simultaneously consider all of the remanufacturing process activities is highlighted by Ijomah et al. (2007), who illustrated that particular product features may simultaneously impact on several remanufacturing activities, and that the nature and intensity of that impact may vary between the various activities. For example, material type influences the remanufacturing steps of cleaning (of core and components), remanufacture components, and test. In all of these process steps, high material strength has positive impact since it enhances durability and hence the potential of the component to withstand the stresses of each of those process steps. On the other hand, product features such as type of bonding may have a positive impact on one remanufacturing activity, and at the same time have a negative impact on another. For example, strong adhesives such as epoxy resin may facilitate assembly due to ease-of-application, but at the same time hinder disassembly. This will hinder component cleaning and internal component rectification because of accessibility issues. This is a key remanufacturing benefit in assisting PSS, since it can help to reduce the service company's financial outlay by providing a lower cost but effective method for maintaining products. Thus, design features that may impede remanufacturing should be identified at the design stage, and investigated to eliminate them or determine how to reduce their negative impacts so that PSS could be optimized.

As Shu and Flowers (1988) also contend, the reliability of the part is very important since it must go through at least one life-cycle, including all remanufacturing steps, and still work satisfactorily. Sundin (2004) has studied which product properties are important to facilitate remanufacturing. By looking at what properties are suitable for the different remanufacturing steps (inspection, cleaning, disassembly, storage, reprocess, reassembly and testing), a matrix called RemPro, shown in Figure 4, was created. In case studies performed at remanufacturing companies in Sweden, Canada and Japan, it was shown that the remanufacturing process steps of inspection, cleaning, and reprocessing were the most crucial (Sundin 2004).

To facilitate these steps, the RemPro-matrix presented below shows that designers of new products should focus on giving the products the properties of ease-of-access and wear resistance, since these are important for both the cleaning and reprocessing steps. Following this, the designer should prioritize the properties of ease-of-identification, ease-of-verification, ease-of-handling and ease-of-separation, since these properties are also included as preferable for the crucial steps, but not to the same extent.

The remanufacturing company should first investigate which steps are crucial for its specific remanufacturing business area and thereafter try to facilitate this according to the RemPro-matrix, as well as place effort on 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 (Sundin 2004). In efforts to use remanufacturing to assist PSS, in addition to decisions on how to design for remanufacturing, consideration should also be given to the need to design the product for remanufacture. Only products satisfying environmental legislation can be introduced into the market. Thus, DFRem guidelines must help to

ensure that products can meet current environmental legislative requirements and have at least good potential to satisfy future ones, either in their original design or because of their ease of redesign after first life. Since products may have different types and levels of environmental impacts at different stages, DFRem guidelines must consider the whole life-cycle to target key environmental impacts and therefore reduce potential penalties. However, research by Ijomah et al. (2007) indicates that there appears to be a lack of DFRem guidelines based on life-cycle thinking.

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

Figure 4. The RemPro-matrix showing the relationship between the preferable product properties and the generic remanufacturing process steps (Sundin and Bras 2005).

## 6. Results of Product/Service System case studies

The results below describe the three companies’ products that were the focus of this study, along with some of the proposed design improvements. Since every case is unique, the following three descriptions do not follow the same template.

### 6.1 Case 1: Forklift trucks

Toyota Material Handling Group (formerly called BT Industries) offers customized material handling solutions to improve its customer’s business efficiency. The group is a complete supplier of manual trucks (i.e. forklifts), electric-powered warehouse trucks and counterbalanced trucks (see example in Figure 5). In order to satisfy its customers throughout the forklift truck’s entire life-cycle, high demands are placed on the product itself and its functionality, as well as on service and spare parts availability. While sometimes the solution is to purchase a new truck, Toyota Material Handling Group’s forklift trucks are being rented with increasing frequency. With rental plans, the customer can attain greater flexibility, reflecting the changing needs of its operations.

Toyota Material Handling Group offers numerous combinations of rental plans, enabling customers to manage truck-related activities with both flexible capacity levels and lower, more predictable costs. Examples of rental programs offered are: *core fleet rental (long-term rental)*, *flexible fleet rental (long-term rental)*, *payback rental*, *short-term rental*, and *standby rental*. According to those interviewed, Toyota Material Handling Group currently manufactures over 40,000 electric forklift trucks per year, and is on pace to

manufacture even more in the year to come. Those interviewed for this study estimated that 50-60 percent of the business for Toyota Material Handling Group Europe was through rental plans.



*Figure 5. An example of how a forklift truck looks and how it is used (Toyota Material Handling Sweden AB 2008).*

Forklift trucks within rental plans are remanufactured by Toyota Material Handling Group in their own remanufacturing workshops. In some cases, the same forklift truck may go out on different rental contracts during a year, and in order to guarantee its quality, the truck is more or less remanufactured between these different rental plans. Since the rental portion of Toyota Material Handling Group is growing, remanufacturing issues are becoming more and more important.

#### *6.1.1. Design improvements*

A forklift truck, used for rental plans, was analyzed from a PSS perspective, e.g. the perspective of use, maintenance and remanufacturing (see further in Sundin et al. 2005b). In this paper, the examples described are of potential design improvements concerning disassembly and maintenance, design solutions, joining solutions and choice of components. There are no in-depth economic calculations or complete drawings in the suggestions, and hence they should be seen as a source of possibilities and ideas for use when designing new products or redesigning existing ones. The economic consequences of these suggestions are not elucidated in this paper, yet they are possible to achieve from a technical perspective.

**Maneuver Consol** – The maneuver consol (Figure 6) in the forklift truck is attached with 11 screws, all of which are inserted from below. The use of all these screws when assembling and disassembling the consol appears to be both unnecessary and time consuming. If a service were to be performed on the consol, it would take an unnecessarily long time to disassemble and reassemble the consol, especially if a single person does it. A suggestion for improvement would be to replace the screws with durable snap-fits. If necessary, for additional securing of the parts, screws could still be used. By using non-destructive snap-fits, the number of screws could be reduced and the disassembly and reassembly facilitated. This would reduce the time of assembly, maintenance and remanufacturing if the parts of the maneuver consol, or its interior parts, needed to be accessed. Furthermore, the plastic cover of the knobs regulating the forklift truck is attached to the maneuver consol with 10 screws. In a similar manner as the suggestion above, the screws could be replaced with durable snap-fits. This improvement would have similar time-reducing effects, especially in the assembly process.

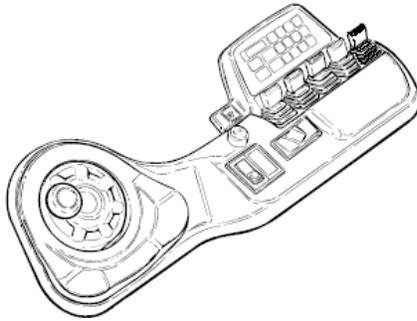


Figure 6. Illustration of a maneuver consol and regulating knobs of a forklift truck.

**Service Door** – To access the engine of the forklift truck today, one must loosen the screw bolt behind the chair and then turn around the steel cover, which is integrated with the chair. This works well as long as one does not need to access the area behind the engine. To change or access any part behind the engine, one must disassemble many parts of the engine, which is time-intensive. A suggestion for improvement would be to install a service door on the outside, as Figures 7a and 7b show. This could also be integrated with an existing door that provides access to the battery. By implementing this suggestion, improved access to the engine would be possible. On the other hand, the stability of the forklift truck would decrease, as the outer steel construction stabilizes the entire forklift truck.

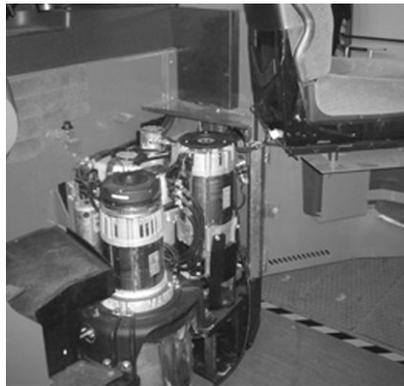
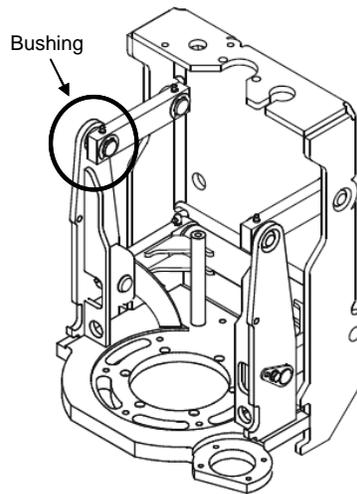


Figure 7a. Current access to the engine in the forklift truck.



Figure 7b. Suggestion of service door implementation.

**Plastic Bushings** – All forklift trucks include engine suspensions as shown in Figure 8. Toyota Material Handling Group has recently changed from metallic to plastic bushings in some of its forklift trucks. In theory, these new plastic bushings are said to be maintenance-free due to lubrication treatment. The problem with this lubrication is that when the forklifts are painted, the grease is dried out and not replaced. During use, the bushings collect dirt and thus the lifetime of the bushings is shortened. Having a broader life-cycle perspective on the use of forklift trucks, the metallic choice would be preferable since it allows easier and better maintenance when the forklift trucks have been used for a few years. The lifetime of the forklift truck depends greatly on the extent of its use and in which working environment. The problem with the plastic bushings is therefore more critical for the forklift truck that runs many hours a day and in dirty environments, such those found in fish processing-related industries.



*Figure 8. Suspension of an engine in a low-lifting forklift truck.*

**Electronic Sockets** – Another example of a suggestion to decrease maintenance is to avoid electronics, which collect dirt. The electronics in a forklift truck are exposed to harsh environments; for example, they are often operated in freezer rooms with temperatures reaching down to -30 degrees Celsius. When the forklift trucks change environments, for example moving between room and freezing temperatures, the electronics are exposed to condensation. These issues should be considered when designing forklift trucks so that the water from condensation does not enter the electronic components and cause shorts or similar problems. The electronic sockets are exposed and inserted from above without any protection from above, as illustrated in Figure 9. As these sockets are placed today, they allow for dirt to be collected and water from condensation to form in small pools.

These problems could be avoided by covering the electronic sockets, or by having them inserted from another direction that would prevent the collection of dirt and water. Another way of dealing with the condensation of water is to build in zones of drainage. This would make the forklift more robust and last longer. The robustness of the electronics is very important when performing maintenance and remanufacturing, since the operations performed are dependant on which codes of errors the forklift truck generates when tested.



*Figure 9. Improper angle of insertion and position of electronic sockets facilitating dirt and water collection without any zones of drainage.*

**General Joining Methods** – In order to facilitate maintenance and remanufacturing, it is crucial to use joining methods that facilitate disassembly and reassembly. In the analyzed forklift truck, a common finding was that several different kinds of screws with various dimensions were used, even in the same modules. When performing maintenance or remanufacturing, the various kinds of screws generate unnecessary, time-consuming operations, for example when operators need seven tools to change the components. Increased standardization of joining methods, e.g. screw dimensions, would save time in the assembly and disassembly processes conducted in production, maintenance and remanufacturing. Using fewer parts also reduces the cost of handling material information such as part numbers in databases.

During the analysis of the forklift truck, there were also some parts that were found to be less accessible due to the arrangement of components, for example, screws that could not be reached with a screwdriver because another component was mounted in front of the screw head. Furthermore, in the existing design there were some components that were soldered and riveted together. These kinds of joining methods make the maintenance and remanufacturing of forklift trucks hard or even impossible to perform. Hence, the number of components that require these kinds of attachments should be reduced for disassembly reasons.

**Crash Guard** – The damage to the forklift trucks could be reduced if a driver log system and crash guards were implemented. Using a driver log system, one can see who has crashed the forklift truck, and with this knowledge the offending driver could be consulted and the overall safety of the driving improved. A drawback to this system would be that the drivers might feel more monitored and less trusted.

#### *6.1.2. Design suggestion validation*

All the design improvements suggested by the researchers were accepted as possible to implement. However, the suggestion of installing a service door for the engine (see Figures 7a and 7b) was not considered a good option. According to the product development manager, the reason for this is that the company did not want to introduce an extra door to the design which might make noise, like the existing door accessing the battery. Furthermore, the extra door would make the forklift truck unstable, as the structure of the forklift truck would be changed.

## 6.2 Case 2: Soil compactors

Swepac International AB in Ljungby is Sweden's market-leading supplier of soil compactors (see Figure 10). The Company offers a full range of products with machine sizes and equipment options for all areas of application. Swepac's aim is to make machines that withstand tough conditions in difficult environments, and its principal customers are earth-moving contractors or plant hire operators requiring machines that do their jobs well and generate revenue. Swepac's machines have been developed to reduce maintenance costs, and have a documented low cost for spare parts and maintenance.

The Company also takes full responsibility for its products after delivery. This means everything from the rapid supply of spare parts, technical support and service, to pure service agreements where the customer as the machine owner can avoid unexpected costs for repairs and spare parts. The customers of Swepac select the level of service agreement in their contracts. Within the terms of these service agreements, Swepac performs maintenance, and for some compactors even remanufacturing, in order to prolong the physical and economic lifetimes of the compactors. However, the designers at the company are aiming to decrease the need for maintenance and remanufacturing, since this creates costs for Swepac. This means, for example, that its future plan is to develop products with longer service intervals, and components and material will be chosen to ensure that they last throughout a normal life-cycle.



*Figure 10. An example of a soil compactor and how it is used (Swepac International AB 2008).*

For this case study, two soil compactors used within their service agreements, models FB-455 and FB-200H, were analyzed from a PSS perspective, namely use, maintenance and remanufacturing (Sundin 2007).

### 6.2.1. Design improvements on model FB-455

The interviews with company management showed that Swepac already had made many improvements in the design of this soil compactor type. In order to avoid unnecessary remanufacturing, the company has introduced new materials to replace the traditional selection. For example, in every compactor made by

Swepac, the bottom plate working against the soil is made of special steel alloy in order to prolong the physical lifetime of their products. Below are additional examples of design improvements implemented in the FB-455.

**The hood** – The hood of the FB-455 compactor is made of colored-through polyethylene plastic instead of painted metal. This means that scratches are not easily spotted, and if there is severe damage to the hood, it can be exchanged with a new one without going through a repainting process. Furthermore, Swepac decided to attach a rubber bellow along the lower parts of the compactor in order to avoid damage to the steel frame holding the product together. An example of a FB-455 that has been specially adapted for a customer is shown in Figure 11.



*Figure 11. The FB-455 soil compactor with plastic hood and rubber bellow adapted for product/service systems.*

**The transport device** – Another example of a design modification to help reduce damage during use is the replacement of the metal loop usually used for transporting the product with a textile strap which includes a chain, as seen in Figure 12. This design change reduces the damage occurring from transports significantly, since it is easier, for example, with a forklift truck, to position the grabbing device (usually a metal hook) in the textile strap instead of the metal loop (see Figure 13). In addition, the friction in the textile strap is greater than that in the metal loop, which could make the compactor slide off the grabbing device (especially if a forklift truck is used). Hence, both the insertion of the moving device and the actual transport of the soil compactor will be safer and less damaging on the soil compactor. One can also see a large difference in the insertion area of the moving device where the textile strap is preferable (Figure 12).



*Figure 12. The FB-455 soil compactor in use with the transport textile strap erected.*



*Figure 13. The FB-450 soil compactor with traditional design with metal hood and metal loop*

**Adapted air filter** – A third example that became clear during the investigation of the FB-455 was that the filter for the air inlet to the engine was specially adapted. Firstly, the air inlet was placed at a spot where fewer particles were flying around in the air. Secondly, the filter was adapted for the soil compactor in a manner that helped it to capture more particles than an ordinary filter could. Since the compactors are used in an extremely particle-filled environment, this kind of filter prolonged the technical lifetime of the engine significantly. Since Swepac was not an expert in the area of motors and how to service them, this was a good option for them to reduce maintenance and repair efforts. The adapted air filter is shown in Figure 14.

**Summary of improvements** – In comparison with the traditional product design of soil compactors (see e.g. the FB-450 in Figure 13), many improvements have been achieved in the FB-455 (see Figures 10 and 11). Examples of improvements of the new design include:

- Less visible damage
- Reduced need for repainting
- Easier change of cover

- Reduced wear during transport
- Safer transport



*Figure 14. The adapted air filter in FB-455 soil compactor.*

#### *6.2.2. Design improvements on model FB-200H*

The FB-200H soil compactor was investigated thoroughly at a Linköping University laboratory. The analysis was performed on the FB-200H during the spring of 2006, when the compactor was disassembled and reassembled several times in order to identify areas where the design could be improved. During the product analysis, several design improvements were elucidated. Some of these improvements are presented below, while the rest are presented in a technical report by Murremäki et al. (2006).

**Snap-fits** – An improvement would be to introduce snap-fits at the strap cover for the strap between the motor and the revolving vibration cylinders. Using snap-fits would eliminate the use of tools, hence making the assembly and disassembly of the cover more time efficient. Snap-fits are preferable if they provide the same quality as the existing four screws do.

**Standardize the screws** – An effective improvement would be to standardize the screws used in the entire compactor design. This would reduce the number of tools used for the assembly and disassembly of the compactor parts. Furthermore, costs would be reduced due to a lower number of articles to keep track of in databases and storage facilities. Most of the screws used in the compactor are shown in Figures 15a and 15b.

**Positioning of the screws** – Another improvement concerns the positioning of screws for the lid to the revolving cylinders chamber. In Figure 16a, the current positioning of the screws is shown; the result is that the assembly and disassembly of the lid in the present design is obstructed by an adjacent part. If the screws can be positioned according to the suggestion in Figure 16b, this obstruction would be less problematic. Changing the positioning of screws will make the assembly and disassembly of the lid go much faster.

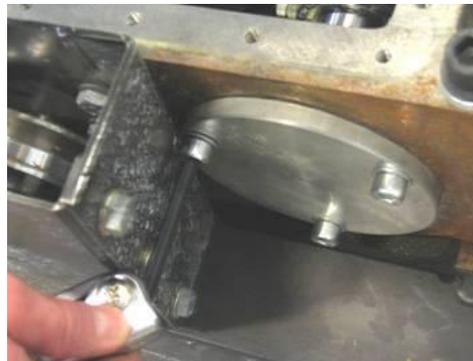
**Drainage hole** – Perhaps the most important improvement suggested was to introduce a drainage hole for the hydraulic oil. Currently, when emptying the revolving cylinders chamber from hydraulic oil, the oil must be pumped from the hole made for the oil fill. This was one of the trickiest parts of the compactor disassembly. The suggested drainage hole would provide for easier changes of hydraulic oil and disassembly of the interior parts in the revolving cylinders chamber. Figure 17 shows where the suggested drainage hole should be placed.



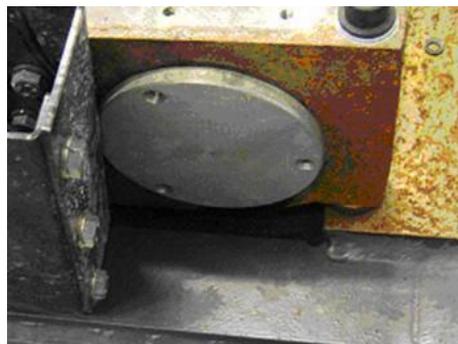
*Figure 15a. Allen key screws used in the FB-200H soil compactor.*



*Figure 15b. Monkey wrench screws used in the FB-200H soil compactor.*



*Figure 16a. Present positioning of screws for the lid to the revolving cylinders chamber in FB-200H.*



*Figure 16b. Suggested positioning of screws for the lid to the revolving cylinders chamber in FB-200H.*

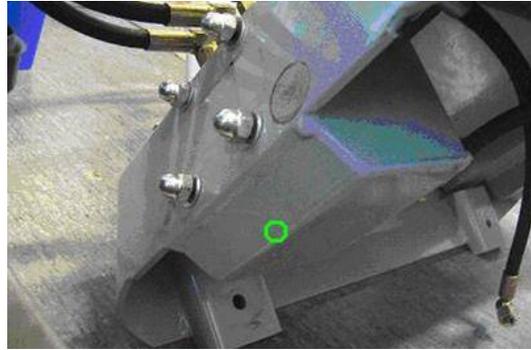


Figure 17. Suggested placement (the circle) of a drainage hole on soil compactor FB-200H.

### 6.2.3. Design suggestion validation

The feedback from the company’s development department was positive. Most of the design changes were seen as easy to implement along with their previously conducted efforts of changing their product design to better facilitate the product/service system.

## 6.3 Case 3: Household appliances

AB Electrolux is a global leader in home appliances and appliances for professional use, selling more than 40 million products to customers in 150 countries every year. The company focuses on innovations that are thoughtfully designed and based on extensive consumer insight, in order to meet the real needs of both consumers and professionals. Electrolux products include refrigerators, dishwashers, washing machines, vacuum cleaners and cookers sold under esteemed brands such as Electrolux, AEG-Electrolux and Zanussi. Consumer Durables account for 93 percent of company sales, and comprise a range of appliances for kitchens, fabric care and floor care.

### 6.3.1. Washing machine

The analysed product – one of the company’s typical washing machines – was manufactured by Electrolux under the brand Zanussi FL12. The washing machine was analyzed from a PSS perspective, i.e. the perspectives of use, maintenance and remanufacturing. The analysed product was in production at the Swedish manufacturer AB Electrolux, and was one of many household appliances that were remanufactured at Electrolux’s remanufacturing facility in Motala, Sweden. Common errors that cause machines to enter the remanufacturing plant are shown in Table 1 below:

Table 1. Examples of errors on incoming washing machine cores.

Faults that lead to scrapping	Faults that are repaired
Cracks on front weights	Engine and electrical errors
Conduit errors	Regulator errors (water level)
Larger flaws on front metal sheet	Minor flaws on metal sheets

The following paragraphs describe how the washing machine is designed and which design improvements have been discovered during the product analysis. The Zanussi FL12 contains five large exterior parts: the top cover, the control panel, a base plate and the front and back steel sheets (Figure 18). All of these parts are

made of plastic, except for the two steel sheets. In the existing design, only the top cover, control panel and back steel sheet are removable, since the ground plate and the front steel sheet are used to stabilize the machine during use.

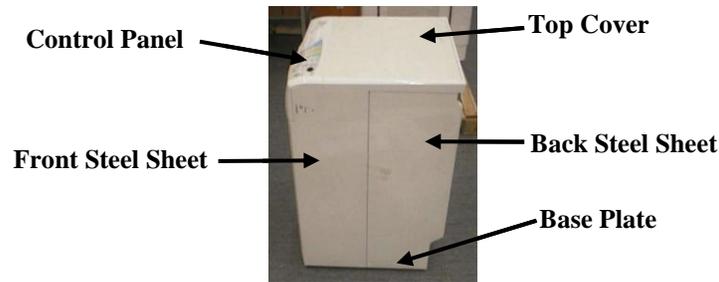


Figure 18. Exterior parts of the reference concept (Zanussi FL12).

### 6.3.2. Design improvements on Washing machine

The design improvements identified below were discussed with Electrolux in order to understand their potential for implementation (Sundin 2001), but whether they have been implemented in new products is unknown. A major problem with regards to repairs and remanufacturing is part accessibility (Sundin 2001). To solve the problem with this particular washing machine model, two new structural concepts were proposed. The conduit of the washing machine is very heavy and thus hard to remove. Therefore, as a starting point it was suggested to change all interior parts without disassembling the conduit. The ease of cleaning was also highlighted as an important design property to enhance the remanufacturing process. In the following paragraphs, structural design changes are first described, followed by the more detailed design changes of the interior parts.

**Reference Concept (Zanussi FL12)** – In the reference concept, the front steel sheet is not removable, and stabilized at the top with a central steel bar (Figure 19). The back steel sheet is removable, as well as the top cover and control panel (In Table 2 the pros and cons of this concept are described.) This existing concept is obviously not designed for maintenance and remanufacturing.

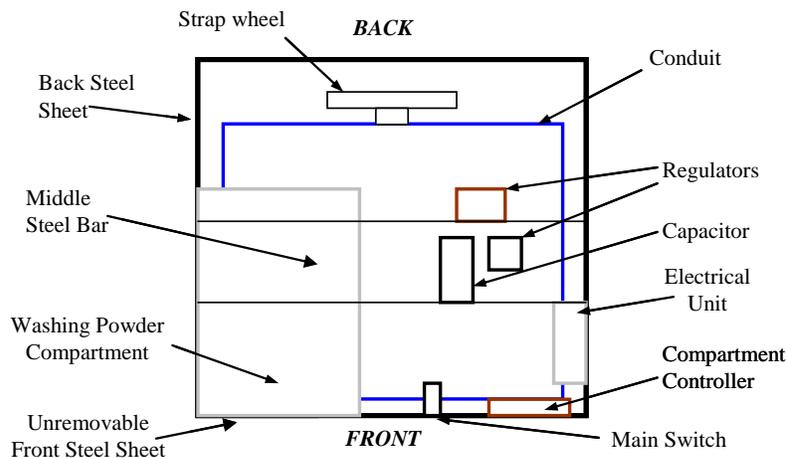


Figure 19. Reference concept (Zanussi FL12) viewed from above.

Table 2. Pros and cons with the reference concept.

Advantages	Disadvantages
Easy to access: - the circulation pump - the back weights - the engine - the strap	The front steel sheet and middle steel bar obstruct access to many interior components  It is difficult to remove: - the front steel sheet and front weights - the arm that controls which powder compartment to flush - the sewage pump and the electrical unit

In order to overcome the disadvantages mentioned above, the following two alternative design concepts have been developed.

**First alternative concept** – In this concept, both the front and back steel sheets are removable, and stabilization is achieved through an internal frame fastened to the base plate (Figure 20). Since the middle steel bar is removed in this concept, a regulator and a capacitor have to be mounted elsewhere, as seen in the top-view picture in Figure 21. Also, in Table 3 the pros and cons of this concept are described.

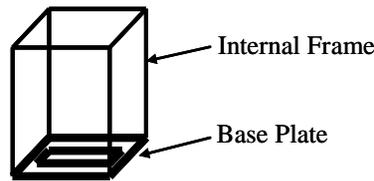


Figure 20. Stabilisation principle for the first alternative concept.

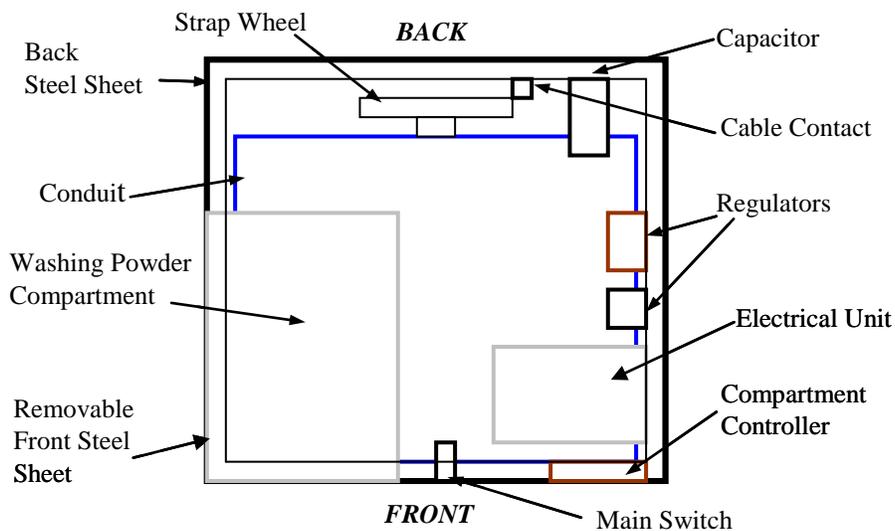


Figure 21. First alternative concept viewed from above.

Table 3. Pros and cons with the first alternative concept.

Advantages	Disadvantage
All exterior parts can easily be removed Increased accessibility without the middle steel bar All weights can be removed	Extra manufacturing costs and assembly costs of the internal frame are required

**Second alternative concept** – In this concept, the front steel sheet functions as a stabilizing part, complemented with a service door at the front (Figure 22). The top frame is used in this concept to house the regulators, the capacitor and the cable contact and for stabilization. This concept has almost the same view from above as the first alternative concept (Figure 21), and is thus omitted here. Table 4 describes the pros and cons of this concept.

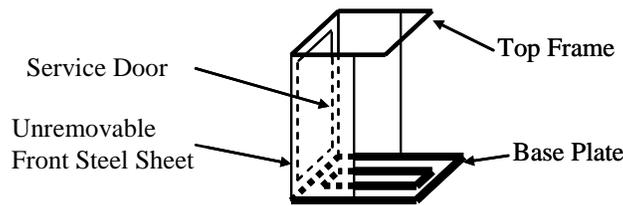


Figure 22. Stabilisation principle for the second alternative concept.

Table 4. Pros and cons with the second alternative concept.

Advantages	Disadvantages
The service door can be removed Increased accessibility is achieved The redesign is minor	The front steel sheet cannot be removed Extra manufacturing costs and assembly costs of the service door are required

**Changes on interior design** – As a compliment to analyzing these large exterior parts and their structure, the interior of the washing machine was also analyzed. The interior parts analyzed included: the door, conduit, engine, regulators, capacitors, heater, circulation and sewage pumps, rubber bellows, front and back weights, cable contacts and shock absorbers. Only the essential design changes that seemed to be most important are described in this article.

**The electrical unit** is not disassembled without difficulty; it is also unsafe to disassemble, since it is easy to cut oneself on it and the cable contacts are difficult to plug in. It was suggested that the box be rotated 90 degrees and fastened with two hooks, a screw and a snap-fit, as shown in Figure 23.

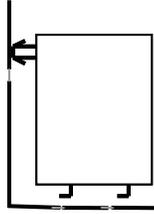


Figure 23. New way of assembling the electrical unit.

**The circulation pump** is troublesome to disassemble, since the screw and the snap-fits holding the pump in place are only accessible from below. In addition, the snap-fits are easily damaged when the pump is disassembled. To assist in the pump remanufacture, all joints should be easily accessible. This can be achieved by having the circulation pump slide into a slot and then fixed with a snap-fit or a screw from above.

**The front weights** must be able to be disassembled if cracked. The accessibility in the reference concept is low, but by choosing one of the structural alternative designs it will increase.

**The cable contact** is currently fastened with a hook, a snap-fit, and a screw, which also connects the ground cable (Figure 24). This appears excessive, and it is therefore suggested that the grounding screw also fix the contact so that the snap-fit can be eliminated.

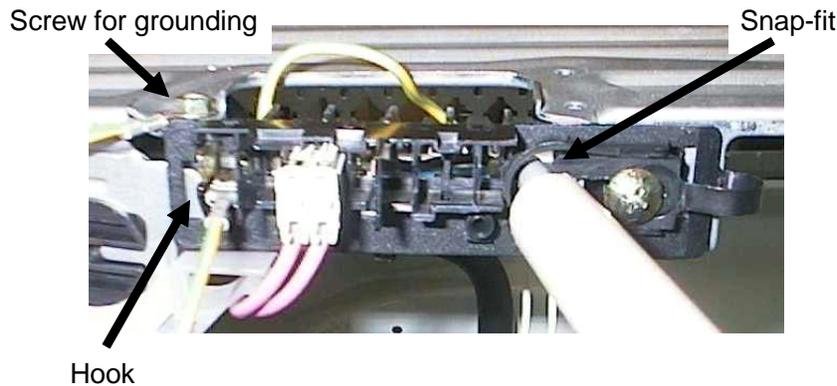


Figure 24. Cable contact in the present design of Zanussi FL12.

The number of screws fastening the circuit card could be reduced from seven to four through the use of a hook instead of screws. The number of screw types in the washing machine is 23, and could easily be reduced through a standardization of screws used as in the case of the soil compactor mentioned in Section 6.2.2.

To conclude the internal design changes, one can say that for the washing machine it is possible to introduce slide slots and snap-fits to enhance maintenance and remanufacturing. Snap-fits are used for easy assembly and disassembly, while slide slots enable a simple fixation in many directions without extra joints.

### 6.3.3. Refrigerator

The refrigerator, model KF 3517, has its surrounding steel sheet as a stabilizing construction. At first glance, it contains few parts that are remanufacturable. The refrigerator has only been analyzed at part-level since it contains relatively few parts: the steel sheets, the doors, the compressor, the shelf tracks and the printed circuit board. The most noteworthy findings are described in following paragraphs.

### 6.3.4. Design changes

Since the *steel sheet* and the isolating foam serve to stabilise the refrigerator, it is hard to change the sheet if damaged since they are glued to one another. There were no satisfactory solutions found for this problem, which should be investigated in more detail.

At the *printed circuit board*, cables are at present designed to hang loose but could easily be gathered in cable sockets instead (Figure 25). This would make it easier to change boards, since the new design would require the remanufacturer only to plug new contacts in instead of resoldering each cable.

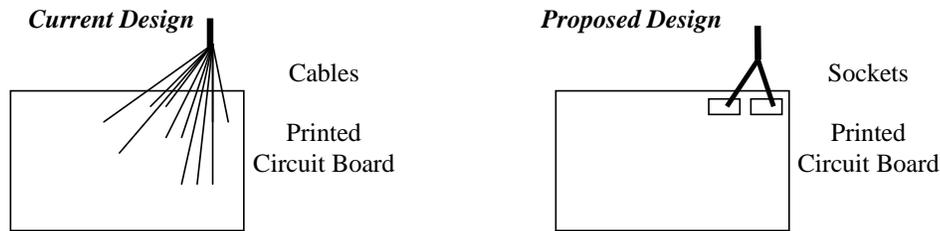


Figure 25. How cables are connected with the current and proposed designs.

Today, the *shelf tracks* are difficult to clean as they are narrow and have sharp edges; Figure 26 shows how they can be redesigned with better accessibility and rounded edges. As a rule of thumb, the radii should be no less than 6 mm (SIK 1997).

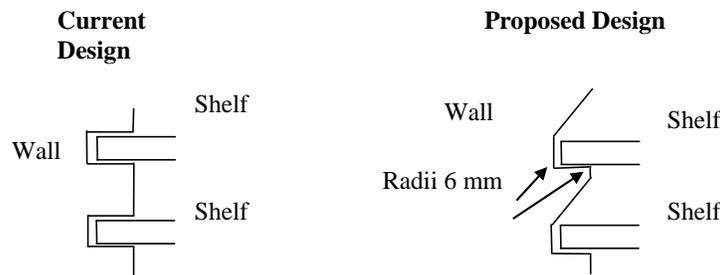


Figure 26. Shelf tracks with the current and proposed designs.

### 6.3.5. Design suggestion validation

The design suggestions for the washing machine were accepted fully by the Electrolux staff. However, the suggestion of the first alternative design, shown in Figures 20 and 21, had already been tried. This concept was found too expensive to manufacture, and therefore was not accepted by the product development teams. Since cleaning is a time-consuming part of the remanufacturing process for refrigerator products, the design suggestion for the refrigerator shown in Figure 26 was highly appreciated.

## 7. Discussion

Increased competition between manufacturers, along with legislative pressure from for example the EU with new directives such as Waste Electrical and Electronic Equipment (WEEE) (EU 2003), work as an impetus for the PSS concept through e.g. remanufacturing. A survey among Swedish remanufacturers also shows that such companies, in general, believe that their remanufacturing volumes will increase in the future (Sundin et al. 2005c). Since remanufacturing is an often useful component in PSS offerings, as shown e.g. in the forklift case, it is likely that use of the PSS concept will also increase in the future. This is also indicated by other studies, e.g. a large study of 40 PSS manufacturing companies in Japan, Germany, Italy and Sweden, as described by Sundin et al. (2009).

The design of products is important when they are to be maintained, and/or repaired/remanufactured. However, for PSS and remanufacturing it is also important to have a well-functioning system of reverse logistics. For example, the relation between the remanufacturer and the customer is important for remanufacturing success. According to Östlin et al. (2008), there are seven different kinds of relations that currently occur between the customer and the remanufacturer. When products are sold through PSSs these kinds of systems are easier to build up, since e.g. the ownership of the products is still with the PSS offering provider.

It is common that when providing PSS offerings, manufacturers often use standard products and do not adapt their products for product/service systems (Sundin et al. 2005a). This could be due to the fact that many products are still sold traditionally to the customer; as the volumes of products sold through PSS increase, however, adaptation of ingoing products to PSS will most likely pay off in the long run. As shown, Toyota Material Handling Group and Swepac International AB have already made adaptations, and have plans to do even more within their PSS. For example, Swepac International AB's designers state that their future plan is to develop products with longer service intervals, and components and material will be chosen to ensure that they last throughout a normal life-cycle.

There are several ways to identify design improvements for PSS. In this study focus was put on maintenance, repairs and remanufacturing. Analyzing the products and having a good knowledge of the product use was also a focus of this study. To have these issues in mind when developing new products the designers can use the RemPro matrix (Sundin and Bras 2005), design guidelines etc. Products' potential for remanufacture can be enhanced using remanufacturability-specific design guidelines (DFRem) and by applying, individually or in combination, other design-for-X (DFX) practices, provided that remanufacturing priorities are considered. Thus, application of design-for-disassembly to remanufacturing is for a special case requiring that parts are not damaged during separation to preserve their "fitness for reuse". Shu and Flowers (1995) exemplify this sentiment by showing that joints designed for ease-of-assembly and recycling may not facilitate remanufacturing because methods assisting assembly do not always support disassembly without component damage. This is not an issue for recycling, but is vital in remanufacturing as components must be "fit for reuse" following disassembly. "Design-for-X" is an umbrella term for the many design philosophies and methodologies developed to address designers' lack of knowledge in important product life-cycle areas. The 'X' in 'DFX' may stand for one of the aims of the methodology, for example assemblability or manufacturability (Boothroyd and Dewhurst 1986, Kuo et al. 2001). DFX practices aimed at integrating environmental considerations into product and process design as well as design-for-environment (DFE) can be particularly applicable to remanufacturing, as seen through developments including the reverse fishbone diagram (Ishii and Lee 1996), the application of modularity and clumping to the recyclability issue (Ishii 1998b) and the End-of-Life Adviser (ELDA) by Rose and Ishii (1999). Other tools developed to assist

DFRem include Repro2, by Gehin et al. (2005), for assessing the remanufacturability of proposed designs via their comparison to current remanufacturable products. Amezcuita et al. (1995) developed guidelines based on design features that assist remanufacturing and use these to identify design changes to improve automobile door remanufacturability. Bras and Hammond (1996) used the Boothroyd and Dewhurst design-for-assembly metrics as a foundation for remanufacturability assessment metrics based on product design features. Mangun and Thurston (2002) presented a decision tool to help decide when products should be taken back as well as the most appropriate component end-of-life options. The tool includes a model to help introduce redesign issues in product design. Ijomah et al. (2007) provide information obtained via industrial case studies and workshops of the features and characteristics that assist and hinder remanufacturing, while Ijomah (2008) provides high-level guidelines to assist DFRem. The high-level guidelines are being used to educate Masters-level design students, and have formed the basis of lower-level guidelines which in turn are being used as the basis for robust design for remanufacturing software tools. An important aspect of incorporating these tools and methods is to have them as useable as possible (Lindahl 2005). Another source of information about product design and remanufacturing would be a report written by Gray and Charter (2007).

DFRem requires products to be designed for ease-of-disassembly, with no damage to the product affecting functional performance for parts hidden from the customer, and no damage affecting performance or aesthetic appearance for parts visible to the customer (or providing good mechanisms to rectify damage). Various DFRem guidelines have been proposed, the most useful being those that are not general guidelines and that also simultaneously consider product features and remanufacturing process activities. This is probably because the most effective way to boost remanufacturing is an integrated product and process design approach (Amezcuita et al. 1996). Research by Ijomah et al. (2007) indicates that there is opportunity to build on previous work by introducing new parameters to enable the development of enhanced DFRem guidelines, for example based on life-cycle thinking. In fact, the World Summit for Sustainable Development (WSSD) identified product life-cycle based tools, policies and assessment tools as key sustainable production requirements (United Nations General Assembly 2002).

## **8. Conclusions**

This paper, which was based on the results of three case studies performed at the Swedish manufacturers Toyota Material Handling Group (forklift trucks), Swepac International AB (soil compactors) and AB Electrolux (household appliances), elucidated how Swedish manufacturers have worked with or could adapt their physical products for product service systems, maintenance, repairs and remanufacture in particular.

To summarize the suggestions for improvements, many of them deal with the accessibility of parts and components that need to be accessed during maintenance and remanufacturing operations. Although there are no economic calculations made, most of these suggestions seem affordable and fairly easy to perform. Many of the suggested (and implemented) design changes are fairly easy to conduct, and many of the adaptations concern disassembly and/or reassembly of product components. These operations are conducted during manufacturing, maintenance and remanufacturing; therefore, in cases where the products are remanufactured several times, these design efforts will have higher impact. In order to identify these kinds of improvements, one can use the RemPro matrix (Figure 4) and/or conduct a product analysis.

From a business perspective, the adaptations have proven positive for Swepac International AB, helping them to achieve a “win-win” situation with the customer. For example, one benefit of having the product adapted for maintenance is that the customer can perform the repairs themselves, something which saves both time and money for Swepac International AB, as it does not need to send out a technician. Also, many of the

adaptations and product training conducted by Swepac International AB are considered as goodwill, and strategically strengthen customer relations.

In addition, the Toyota Material Handling Group has experienced positive effects in its adoption of PSS, and its number of rental plans is increasing, along with greater profit margins than those sold via traditional product selling. In general, the Group's forklift trucks have easy-to-perform maintenance and remanufacturing. However, some improvement in design could be conducted as shown in this paper. Due to the increased volumes of products being sold through PSS offerings, these design issues need to be considered on a larger scale, such as seen at Toyota Material Handling Group.

Concluding this paper, product/service systems place new requirements on products in comparison to traditionally sold products. Although the PSS approach may be profitable with or without remanufacturing with existing product design they can be improved. With a more optimized product design, obstacles can be reduced and profits increased. The product used in product/service systems should have easy-to-perform maintenance and remanufacturing/repairs in order to reduce costs. The results of this paper have shown and conclude that designers can conduct many changes in order to facilitate product/service systems.

## **9. Future research**

For the future, it would be interesting to uncover any additional product requirements needed for a successful product/service system not addressed in this paper. For example, it could be interesting to explore which product data could be collected during use in order to improve the products' different life stages. Additionally, research could be undertaken to enhance the robustness of current design-for-remanufacturing methodologies, thus furthering the potential of remanufacturing in improving companies' product/service systems.

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