DESIGN AND DEVELOPMENT FOR EFFECTIVE REMANUFACTURING TOWARDS A NEW SUSTAINABLE PROSPECT

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Abstract - *In this dissertation, in order to address the research objective, five research questions were set. In this kind of research the amount of time and resources is limited. Eespecially in Maharashtra, India, the researcher had to gather data from overseas studies, the number of remanufacturing companies with industrial process is low. Therefore, the studies have not been conducted in depth but this has not been seen as to affect the research results. This is due, since the research have been on a high and not detailed level concerning remanufacturers opinions of driving forces, costs, bottlenecks in the process etc. Hence, the main characteristics of the remanufacturing facilities have been identified. Furthermore, the conducted RPAs have complemented the overall picture of the analyzed remanufacturing facilities. The research has, moreover, also concerned more in depth studies at the remanufacturing facility operated by Whirlpool India Ltd. In Ranjangaon, Pune. The Whirlpool India Ltd. studies have in many ways worked as a base for the latter parts of the research. The environmental aspects of remanufacturing have been elucidated in comparison with those generated by new manufacturing and material recycling.*

Key Words: **Remanufaturing, Cost, RPA, Material, Recycling**

1.1 Environmental Perspectives on Remanufacturing:

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

1.1.1 Literature Study:

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

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

Another study analyzing environmental and economic perspectives on the remanufacturing of gasoline engines was conducted by Smith and Keoleian (2004). They developed a life-cycle assessment (LCA) model in order to investigate energy savings and pollution prevention that were achieved in the United States through remanufacturing of a mid-sized automotive gasoline engine. Furthermore, a comparison was made to an original equipment manufacturer manufacturing a new engine. A typical full-service machine shop, which is representative of 55 percent of the engine remanufacturers in the United States, was inventoried, and three scenarios for part replacement were analyzed. The life-cycle model showed that the remanufactured engine could be produced with 68 percent to 83 percent less energy and 73 percent to 87 percent fewer carbon dioxide (CO_2) emissions. Furthermore, the model showed significant savings for other air emissions as well, with 48 percent to 88 percent carbon monoxide (CO) reductions, 72 percent to 85 percent nitrogen oxide (NO_X) reductions, 71 percent to 84 percent Sulphur oxide (SO_X)

reduction, and 50 percent to 61 percent non-methane hydrocarbon reductions. Raw material consumption was reduced by 26 percent to 90 percent; solid waste generation was reduced by 65 percent to 88 percent. The comparison of environmental burdens was accompanied by an economic survey of suppliers of new and remanufactured automotive engines showing a price difference for the consumer between 30 percent to 53 percent for the remanufactured engine, with the greatest savings realized when the remanufactured engine is purchased directly from the remanufacturer. (Smith and Keoleian, 2004)

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

Apart from studying the analyses conducted by Kerr (1999) and Smith and Keoleian (2004) the author developed and supervised an own analysis in cooperation with a colleague17. The actual analysis was conducted by four master students. Next section will describe the results from the analysis.

1.1.2 Refurbishing Versus Recycling at Whirlpool India Limited:

The analysis was primarily an environmental comparison of two end-of-life scenarios for two household appliances. Whirlpool India Ltd. often experiences that household appliances are being broken down during use or damaged during transportation. These broken/damaged appliances arrive to various service centers all over India. In the first scenario the appliances are material recycled close to the service centers. In the second scenario (existing), the appliances are transported by heavy trucks and remanufactured in a facility in Ranjangaon, Pune. The methodologies used were LCA modeling and ABC as earlier mentioned in Chapter 3. This analysis included both an environmental part and an economic part. The products that were analyzed were a washing machine and a refrigerator (combined refrigerator/freezer). The two different scenarios of remanufacturing and material recycling are shown in Table 8 as well as the figures for new product manufacturing ('New Prod.'). In the scenario for remanufacturing the part going to material recycling is included. In this case the figure is 16.7 percent, i.e. 83.3 percent of the products coming to the remanufacturing facility are remanufactured and sold back to the consumer market. As 16.7 percent of the refurbished products are material recycled this share is accounted for and shown in brackets in Table 6. For example, for the first refurbishment estimation, 'nonrenewable material (kg)', for the refrigerator the figure in brackets derives from: 1.4 + 0.167 • 0.8 = 1.5.

Functional Unit	Refrigerator			Washing Machine		
Scenario	Rema-nufact.	Recycle	New Prod.	Rema-nufact.	Recycle	New Prod.
Resources						
Non-renewable material (kg)	1.4 (1.5)	0.8	189.4	1.5 (1.5)	0.1	120
Renewable material (kg)	0.2 (0.2)	-	1.1	0.2 (0.2)	-	2.0
Energy (kWh)	20 (23)	16	1182	24 (24)	2.8	750
Emissions						
Greenhouse Gases (kg CO2-equivalents)	2.5 (3.7)	7	214	2.4 (2.4)	0.2	160
Acidifying gases (mol H+-eq)	0.0004 (0.2)	1.4	19.5	0.001 (0.01)	0.04	29.1
Ground level ozone gases (kg C2H4equivalents)	0.002 (0.004)	0.009	0.004	0.002 (0.002)	-	0.1
Eutrophication						
compounds (kg O2equivalents)	0.2 (0.2)	0.3	14.3	1.3 (1.3)	0.05	2.5
Recyclable resources						
Materials (kg)	0 (12.7)	76.4	6.4	0 (7.5)	45.1	5.2
Waste						
Hazardous (kg)	0.003	-	0.23	0.00 (0.09)	0.5	2.0
General (kg)	1.1 (3.3)	13	160	1.3 (1.3)	0.1	198

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

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

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

All in all, from an environmental point of view, remanufacturing seems in this analysis to be a sound way to achieve functional products. The remanufacturing process results in a functional product, while recycling only provides material. A negative aspect, compared to recycling, is the need for longer transports as Whirlpool India Ltd. has only one refurbishment facility in India. By using sophisticated logistics in cooperation with transport companies, the amount of transports needed has been minimized. Energy consumption at the facility is fairly small, as most of the work is done manually. In comparison to the production of a completely new product, the emissions and energy needs resulting from refurbishment are very small. The amount of energy needed to produce a new refrigerator is 50 times greater than the energy needed for refurbishment. The production of a new washing machine requires 30 times more energy than the refurbishment of such a product. Similarly, the need for material resources is much greater when producing completely new products. The usage of materials is becoming an important issue, as non-renewable resources are diminishing.

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

Parallel to the ecological calculations an economic analysis of the scenarios was conducted. It is clear that the refurbishment scenario results in more costs than the recycling scenario. One reason for this is that refurbishment is a value adding process and it takes significant efforts to add value to an old household appliance. The recycling process, on the other hand, only adds limited value to the product. The process just puts the appliance in a shredder and the different materials are sorted for recycling. One should also take into account that the refurbishment process generates an income and a positive environmental image for Whirlpool India Ltd. The refurbished products are sold to retailers and with the income from the retailers the costs that accrue in refurbishment can be covered with a good marginal. Depending on what kind of cosmetically flaws the refurbished appliances have they are sold to the retailers at a price range of 50 to 75 percent of the ordinary manufacturing price. The amount of overhead costs in refurbishment is considered high (about 70 percent), because the refurbishment process, for example, only uses spare parts that are disassembled from old products. Therefore, there are large storage areas for spare parts and products that are waiting for spare parts that are not in stock at that particular time. Despite these expenditures, the process for refurbishing household appliances was found profitable. In the recycling scenario, costs were analyzed on a higher level than in the first existing refurbishment scenario. A full scale working system for the systematic recycling does not yet exist. Therefore, the recycling scenario was analyzed by conducting cost estimation. It was found that for recycling, the costs derived from transporting, collecting and recycling of the appliances. The main idea with recycling activities differs economically from the idea with refurbishment. For refurbishment there are really possibilities to get an income from the refurbished products, because they have quite a big economical value after the process. In addition, the refurbishment process adds value to the product, whereas the recycling process normally does not. In the recycling process, the products are shredded and recycled into different raw materials, which can then be reused in some different value-adding process.

Finally, when summing up the different results of the analyses, one can see that the studied and performed analyses show that remanufacturing is in general preferable to other end-of-life scenarios or new production from an environmental perspective, having in mind that the remanufacturing process results with a functional product. These results go in line with the end-of-life priority lists stated by Graedel and Allenby (1996) and Ryding et al. (1995) (see Section 2.5.2). Furthermore, it was shown that the refurbishment of household appliances in the Ranjangaon, Pune facility was profitable as well as the study conducted by Smith and Keoleian (2004). One must also consider the value of reselling the product, environmental image, costs and loss of yield for new manufacturing (applicable if they are in the same market). These issues are further elaborated in the remanufacturing case studies described in Section 4.4. These results are also discussed in Paper Jacobsson N. and Björkman

1.2. The Generic Remanufacturing Process

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

According to experiences of study visits by the author, remanufacturing companies choose different sequences of executing the remanufacturing steps. For example, the cores could either be disassembled followed by inspection (e.g. error detection) or the inspection could be the first step, without first being disassembled. In research, the remanufacturing process often is described with the inspection step taking place after the cleaning and disassembling steps (see e.g. Steinhilper, 1998; Smith and Keoleian, 2004). This is not always efficient, however, e.g. if the product has fatal errors, it will be useless to remanufacture. In practice, a visual inspection for major defects is almost always performed as part of product sorting when products arrive at the remanufacturing facility. However, detailed inspections are easier to conduct when the product has been cleaned. Hence, every remanufacturing process is unique and it is always necessary to choose a strategy for efficient remanufacturing as well as one that matches the type of product being remanufactured. The steps in the remanufacturing process could therefore be arranged in a different order, or some steps could even be omitted, depending on the product type, remanufacturing volume etc. An example of how products are remanufactured in the remanufacturing plant in Ranjangaon, Pune is shown in Figure 4.1.

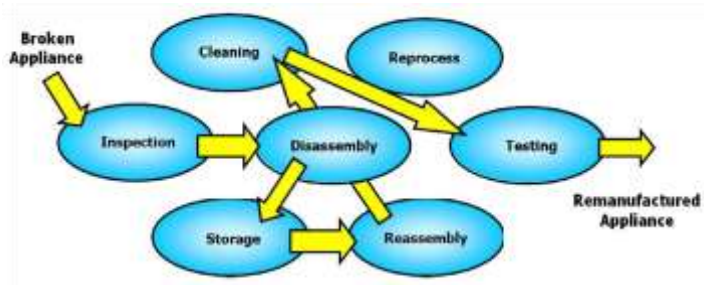


Fig: A step sequence of household appliance remanufacturing at whirlpool India Pvt.Ltd., Ranjangaon, Pune.

In this example, the products are first inspected in order to locate the problem of the product. Secondly, broken parts are disassembled and the remains of the product are being stored. The product is then reassembled with new spare parts or spare parts from other products. Finally, it is cleaned and tested to ensure it works properly. The product is now remanufactured and ready to be shipped out to a retailer once again. Note that the repair step is omitted in this example since broken parts are replaced with new parts or spare parts. Another example, from 'Cummins Generator Technologies India Pvt. Ltd', Ahmednagar, is shown in Figure 4.2.

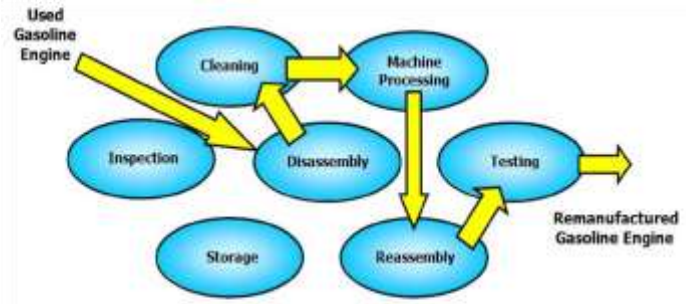
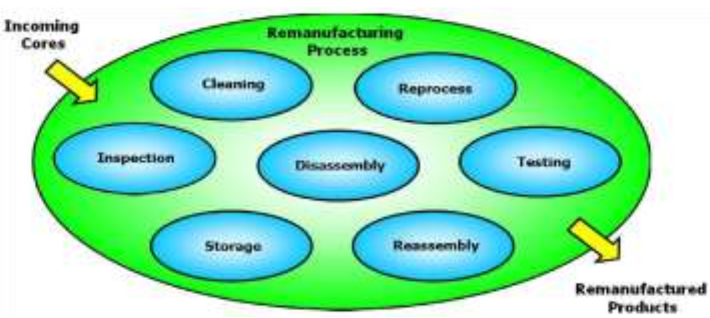


Fig 4.2: A step sequence of gasoline remanufacturing at 'Cummins Generator Technologies India Pvt.Ltd. Ahmednagar.

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

These two cases show two different ways of arranging the remanufacturing steps. In these remanufacturing processes, internal transports and packaging of the products are not considered as remanufacturing process steps. In Paper, Product Properties Essential for Remanufacturing by Sundin E. (2001) a generic remanufacturing process is described based on other researchers' results and by looking at the Whirlpool India Ltd. Ranjangaon, Pune. To verify and possibly refine the generic remanufacturing process further, six remanufacturing case studies were performed (also related to research question 4). Combining the literature study and the remanufacturing case studies we receive the following result of a generic remanufacturing process shown in Figure 4.3.



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

In many generic remanufacturing processes a specific step sequence is shown (see e.g. Steinhilper, 1998). In this model, see Figure 4.3, the possible steps are shown without any specific order. The sequence that the remanufacturing process has is dependent on many things such as; product design, working environment, volumes etc. These results are further discussed in Paper Product Properties Essential for Remanufacturing and An Economical and Technical Analysis of a Household Appliance Remanufacturing Process by Sundin E. (2001) respectively.

1.3 Preferable manufacturing product properties

As a continuation of identifying the generic remanufacturing steps, it was a challenge to identify the preferable product properties for each step. Once again, previous conducted research and my own research conducted in Linköping were combined in order to address the third research question stated in Section 1.3. The research related to this research question is mainly described in Papers Enhanced Product Design Facilitating Remanufacturing of two Household Appliances - A case study, an Economical and Technical Analysis of a Household Appliance Remanufacturing Process and Refurbish or Recycle Household Appliances? An Ecological and Economic study of Electrolux in Sweden (2001) and Tyskeng S. (2003) respectively. All the product properties from the steps in the generic remanufacturing process (Figure 4.3) can be condensed into the following matrix (see Figure 4.4 below) of remanufacturing product properties - the Remanufacturing Property Matrix (RemPro)

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

The RemPro-matrix illustrated above shows which product properties are preferable for the different steps in the remanufacturing process. The RemPro matrix could further be used as a design tool. Using this matrix, the designer can easily see what properties that are needed for the different steps; depending on which product is being designed, any step can be of particular interest and therefore emphasized. The RemPro-matrix can be used in, for example, the cleaning phase. In this case, the product parts should be 'easy to access' and the material should 'resist the cleaning solutions'. At inspection, on the other hand, it is important to easily 'verify what the product or product part condition' has. Furthermore, for the inspection step, it must be 'easy to identify' the parts and testing points which should also be easy to access. It is important, though, to have the whole remanufacturing process in mind when designing products for remanufacturing. For example, single focus on one step could make other remanufacturing steps too difficult or expensive to carry out. One must remember that the essential goal in remanufacture is part reuse. If a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly will not be a factor (Shu and Flowers, 1998). This means that much effort can be made in product design without getting the expected benefits. As Shu and Flowers

(1998) also declare, the reliability of the part is very important since it has to go through at least one life cycle, including all remanufacturing steps, and still work satisfactorily.

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

Since the remanufacturing process includes many steps, there are some essential properties that the products need to have in order to be remanufactured in an efficient manner. When studying literature about remanufacturing processes and analyzing then Whirlpool India Ltd. Ranjangaon, Pune facility to find out what kind of product properties are important for the different remanufacturing steps, the following four properties were found to be most frequently important for products, and its parts:

- Ease of Access,
- Ease of Identification,
- Wear Resistance And Ease of Handling.

Theoretical studies and the case studies at Whirlpool India Ltd. Ranjangaon, Pune resulted in these product properties. The above stated properties provide the solution to the third research question stated in Section 1.3.

1.4 Results from remanufacturing case studies:

Addressing the fourth research question, a case study including six different remanufacturing companies was conducted. The case study methodology is described in the research methodology chapter, where, for example, the method for rapid plant assessment (RPA) is described. These case studies have not been published; instead the case study reports are included as Appendix A. In this section the results from the individual case studies at the remanufacturing facilities will be described briefly. The results from the remanufacturing companies are described in the following order:

- 'Vishesh International', Malad, Mumbai
- 'Go Print'
- 'Cummins Generator Technologies India Pvt. Ltd' Signal Circuits Pvt. Ltd.
- MAN Trucks India Pvt. Ltd.
- Whirlpool India Ltd.

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

1.4.1 Vishesh International:

The first case study was conducted at 'Vishesh International', which is a small remanufacturer of toner cartridges in Malad, Mumbai. It is a small family-run business and has one remanufacturing facility with 17 employees. The most important driving force for starting the business was, naturally, to gain a profit. A secondary driving force was to contribute towards stemming the flow of garbage going to landfills. At the facility, toner cartridges are remanufactured, mostly from laser printers, photocopiers and fax machines. It is only the cartridges and some other parts for printers that are remanufactured. Currently the volume of remanufactured cartridges is 1300 a month but the goal is to reach 2000. The remanufacturing of cartridges has following step sequence: Receive empty cartridges from customer

1. Disassemble
2. Clean
3. Separate parts
4. Toner refill
5. Reassemble
6. Test
7. Package

Rapid Plan Assessment:

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

Company Analysis:

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

A problem with this type of operation is that the original manufacturer competes on the same market by offering new cartridges. Having the same customers affects the design of the cartridges negatively from a remanufacturing perspective. Hence, the products are not designed for remanufacturing. If the OEMs had their own remanufacturing business, the cartridges would most likely have been adapted for remanufacturing. Now, when independent remanufacturers remanufacture cartridges to the same market, the cartridges are optimized for new manufacturing. Due to this, the customer ends up paying more for the remanufactured cartridge than actually would be needed.
Since volumes are rather low (16000 cartridges per year) and number of products is high (160), it is of the utmost importance to have a flexible process. This is through the use of manual operators, who can perform every step in the remanufacturing process. Cleaning and toner refill are the steps that allocate the longest time in the process. The Company could prepare to buy a filling machine as suggested to improve at least the filling step. A second testing machine should be installed in order to speed up the process.

1.4.2 Go Print:

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

At the facility, toner cartridges are remanufactured, mostly from laser printers, photocopiers and fax machines. Currently the volume of remanufactured cartridges is 210000 annually. The remanufacturing of cartridges has following step sequence:

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

Rapid Plan Assessment:

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

Company Analysis:

'Go Print' has relatively high product volumes (210000 annually), which gives it good possibilities for using lines in its remanufacturing process. As the process looks today, it is largely station-based. The remanufacturing steps could be situated more closely together to avoid unnecessarily long transports. Furthermore, the steps of disassembly, reassembly and testing could be more streamlined with parallel flows for different kinds of products. This change would most probably increase the efficiency of the remanufacturing process. The operators need to go several times to the bench for disassembly/reassembly and the testing area before having the cartridge delivered to the following step.

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

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

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

1.4.3 Cummins Generator Technologies India Pvt. Ltd.:

The third case study was conducted at 'Cummins Generator Technologies India Pvt. Ltd', which is a large remanufacturer of automotive and non-automotive gasoline engines in Ahmednagar, Maharashtra. The main goal of this business is to make money and 'Cummins Generator Technologies India Pvt. Ltd' does this through remanufacturing. There are other considerations such as plant capacity of original engine manufacturing to provide capacity, hence they could utilize their equipment for new manufacturing and 'Cummins Generator Technologies India Pvt. Ltd' will provide the capacity through remanufacturing operation. Recycling of parts (remanufacturing) is a good thing to do from a business standpoint. Worldwide there are over 2000 employees in both new and remanufacturing operations and within this facility there are 180-200 approximately focusing on non-Cummins products. The remanufacturing process at 'Cummins Generator Technologies India Pvt. Ltd' include following steps:

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

Rapid Plan Assesment:

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

Company Analysis:

'Cummins Generator Technologies India Pvt. Ltd' has dealt with remanufacturing for a long while (18 years) and is one example of a remanufacturing business that started during the remanufacturing boost that started during and after Industrial Revaluation in Maharashtra. The Company is certified with quality and environmental standards, which can be noticed, in their remanufacturing process. For example, environmental issues regarding packaging, chemicals spills and processes are regarded.

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

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

1.4.4 Cross Case Analysis:

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

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

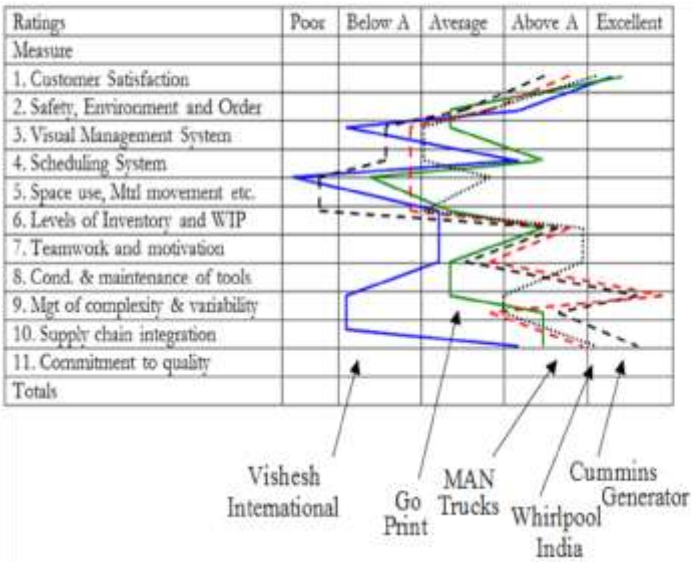
  ('Vishesh International', 'Cummins Generator Technologies India Pvt. Ltd' and Whirlpool India Ltd.)
- Inspection is a crucial step at two of the companies ('Go Print' and Signal Circuits Pvt. Ltd.)

Table 7 shows a list over the companies being analyzed. The total RPA score from the

RPA scoring sheets are very similar going from 55 to 57 excluding the score for 'Go Print', which has a score of 65.

Company	Product	Type	Volume	RPA
'Vishesh International'	Toner Cartridges	Independent	16 000	55
'Go Print'	Toner Cartridges	Independent	240 000	65
'Cummins Generator Technologies India Pvt. Ltd'	Gasoline Engines	OER/Contracted	Confidential	57
MAN Trucks India Pvt. Ltd.	Diesel Engines	OER	150	57
Whirlpool India Ltd.	Household Appliances	OER/Contracted	5 500	57
Signal Circuits Pvt. Ltd.	Single-use Cameras	OER	36 000 000	-

It is hard to draw any conclusions from Table 4.2 rather than that one company seem to be more efficient (from a lean perspective) than the others. This could have to do that 'Go Print' holds an ISO9001 certificate and have a high volume of remanufactured products that makes it easier to be efficient and the cartridge types being remanufactured are rather similar. Instead of only looking at the aggregated RPA-score it is, at least in this study, more interesting to compare the RPA scoring sheets viewed in Table 4.3 below.



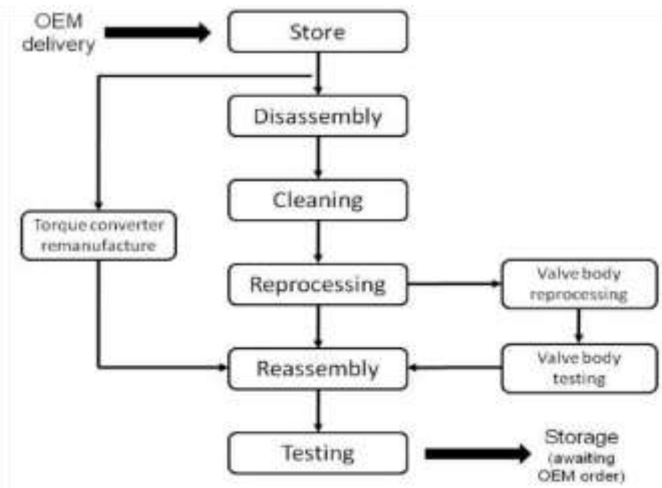
In general there is a low score on the measures 3, 5 and 6 which represents: Visual Management Deployment (3), Product Flow, Space Use and Material Movements (5) and Inventory and WIP Levels (6). Furthermore, there is a high score on the measures 1, 7, 9 and 11 which represents: Customer Satisfaction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

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

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

1.5 Design Documents:

A key barrier to effective remanufacture was lack of design information. The remanufacturer did not have access to the original design documents, despite having direct links with the original manufacturer. The reason behind this is clear: protection of intellectual property (IP). If an OEM (original equipment manufacturer) were to provide their contractor with key design information, there could potentially be an information security risk from the OEMs competitors (who may use the same contract remanufacturer). However, this IP sticking point means that cores are remanufactured based upon reverse engineering, a complex and time-consuming task that is unlikely to be 100% accurate.



Design Problems: Durability:

One key design-related problem the remanufacturer faced was durability. Durability is a key feature in DfRem guidelines, yet the company has been experiencing a significant drop in durability over the past few years. Lighter, less durable materials are increasingly being selected in automotive design because they reduce the weight of the vehicle and therefore reduce fuel consumption, a clear environmental benefit. However, these products wear out at a much faster rate than previous designs, and when sent for remanufacture, have to be discarded more frequently, or at least are more difficult and costly to return to like-new condition. Clearly this is costly for customers and should be undesirable to OEMs too, as they are paying for the remanufacturing services. This is a good example of the many conflicts in DfRem: the conflict between improved environmental performance and retained remanufacturability. Furthermore, the increasing use of plastics in automotive products presents a similar problem: these materials are cheaper to produce yet are impossible to remanufacture and must be replaced, making the remanufacturing process more costly.

OEM Feedback:

Whilst the remanufacturer would regularly provide 'diagnostic' feedback relating to specific product failures and faults, they were unaccustomed to providing DfRem (i.e. design optimization) feedback to the OEM. Overall communication with the OEMs was considered a complex, slow and generally unrewarding procedure. One reason given was the globalization of the company's clients: the management responsible for making design changes may be located in another country. It is also possible that being acclimatized to design norms and the same working conditions over time means that personnel at a remanufacturing plant are unable to recognize product designrelated issues.

Confab:

Mapping the organizational conditions that enable DfRem to be integrated into the design process, beginning with a review of the literature followed by a pilot study of a remanufacturer's problems and OEM-remanufacturer relationship issues that could affect the integration of DfRem into the design process. The preliminary findings from one automotive contract remanufacturer have raised some issues that should be taken into further consideration. A common criticism of current DfRem guidance is that it lacks lifecycle awareness (Ijomah W, McMahon C, 2007 & Shu L, Flowers W. 1999). The fact that the used products in the study had been designed for optimal environmental performance- thus hindering effective remanufacture- would suggest there is truth in this concern, as well as suggesting that remanufacturing concerns are not perceived to be of primary concern in new product development. Any approach to integrating DfRem would have to acknowledge this.

Lack of design feedback could be a major issue affecting DfRem's stance in the design process: it is possible that designers are not considering remanufacturing issues simply because they are not aware of them. Previous researchers have suggested that designers may be lacking in the necessary knowledge to carry out effective DfRem (Ijomah W, McMahon C, 2007 & Charter M, Gray C. 2008) and therefore feedback from the remanufacturer may be key to raising awareness. Whether lack of communication is due to OEMs not listening, remanufacturers being acclimatised to problems, or a combination of both, remains unclear.

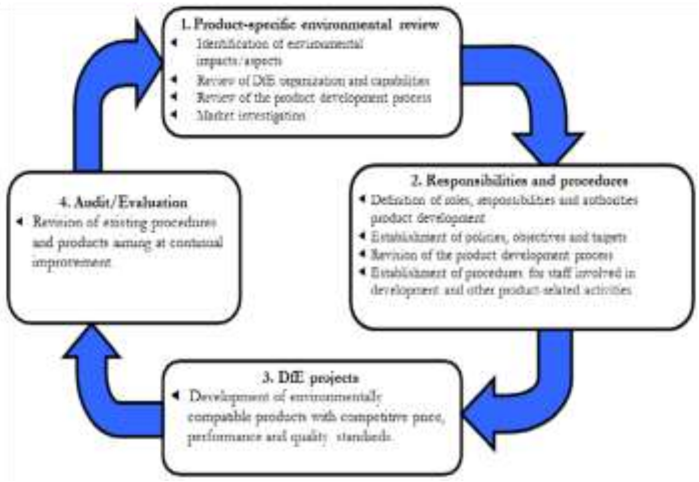
The remanufacturer observed in the pilot study was working under contract with automotive OEMs. As most previous discussions around DfRem have mainly been concerned with OEM remanufacturers, the specific issues of this relationship remain little explored. Preliminary findings would suggest there is a lack of trust between OEMs and contract remanufacturers that is hindering the flow of design information and discussion. If this restriction on communication was found to be unavoidable, it may be deduced that DfRem is indeed only feasible when the OEM is directly involved in remanufacture.

1.6 Integration of DfRem aspects into EMSs:

The fifth and last research question deals with how the integration of design for remanufacturing (DfRem) aspects could be better integrated into a company's environmental management systems (EMSs). As described in the methodology a wider scope was taken to address this research question. Instead of only looking at aspects of DfRem, which could be seen as a part of DfE, all aspects of DfE were considered. This section briefly describes the results from this investigation, which is described in more detail in paper 'Products in Environmental Management Systems: Drivers, Barriers and Experiences' and paper 'Products in Environmental Management Systems: the Role of Auditors' by Ammenberg J. & Sundin E. (2004) respectively. This research project started off by conducting a literature study of what the experiences of DfE integrated into EMSs were. These kinds of EMSs are, in research, sometimes called product oriented environmental management systems (POEMS). As a result of the literature study, external auditors were found as key persons for the DfE integration. Hence, the external auditors were studied more closely in order to identify their role of integrating DfE and EMS.

1.6.1 Experiences found from the literature study:

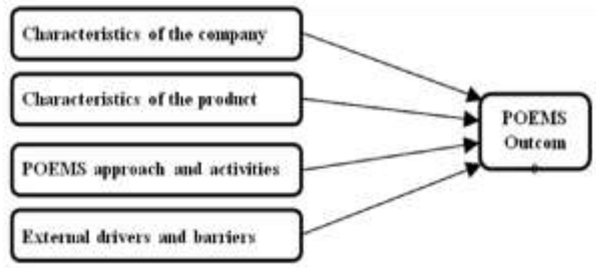
A cursory study of different POEMS models, e.g. models presented by Cramer and Alders (1999), Karlsson (2001), Klinkers et al. (1999), Rocha and Brezet (1999), and Rocha and Silvester (2001), show that they are quite similar on a general level. However, different terminology is used and the categorization of what belongs in the different steps in the PDCA cycle varies. On an overall level, and based on the references cited above and the authors' own experience, the following general steps of most of the product-related parts of a POEMS model can be stated as the PDCA cycle shown in Figure 4.6 The described process is mainly focused on the first implementation of a POEMS, which could be carried out by companies with or without an existing EMS or other management systems.



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

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

To what extent companies are willing and can manage to integrate DfE aspects into their management systems is dependent on many different factors. It appears reasonable to assume that what is an important factor for DfE or EMS individually is also important concerning their integration. Accordingly, success factors, drivers and barriers that have been presented in literature as important for either one of the concepts have been gathered and categorized into four different levels, as shown in Figure 4.7 The ingredients of each level are all affecting to what extent DfE and EMS are integrated and/or the outcome of such integration.



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

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

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

1.6.2 Experiences from external EMS Auditors:

The significant environmental aspects are the foundation stones around which the EMS is built. Consequently, to a large extent, the environmental effectiveness of these systems depends on the extent to which products and product-related aspects are classified as significant. The answers relevant to this issue indicated that issues concerning the whole product seldom are judged as significant aspects and sometimes they are not considered as environmental aspects at all. This means that attention is seldom paid to product characteristics such as resource demands during the use phase, impacts during the end-of- life phase, recyclability, etc.

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

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

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

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

A majority of the auditors said that they have great possibilities to strengthen the connection between DfE and EMS. Only a few of them asked for tougher standard formulations regarding products, while others wanted clarifications rather than stronger requirements. Judging from these impressions and comments, it is a hot issue concerning to what degree auditors is allowed to function as consultants. Many interviewees spontaneously mentioned that they transfer information to companies that are not competing.

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

1.6.3 Comparison of Auditors:

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

- To what extent products are considered as significant environmental aspects (Often; it depends; seldom)
- If environmental considerations are required in product development (Yes; I try to influence; no)
- What these requirements encompass

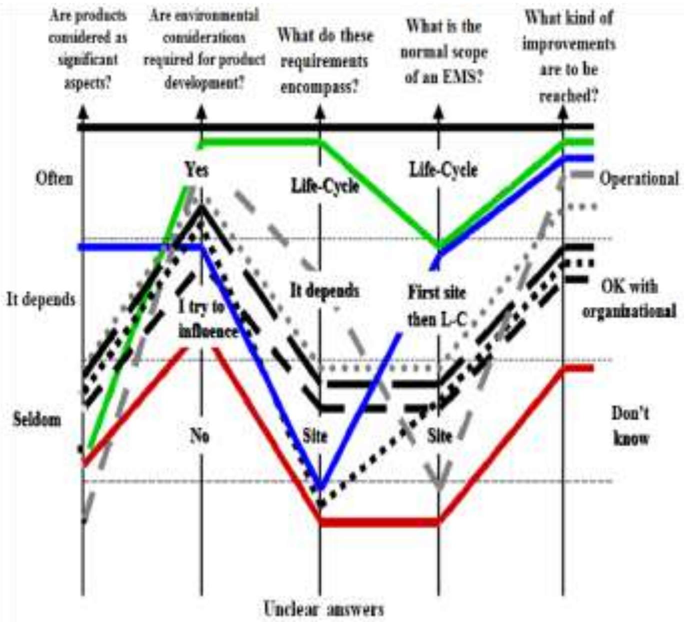
(Life cycle; it depends; site)

The Scope of EMS

(Site + other important parts; first site, then life cycle; site)

What kind of improvements are required to be reached (Operational; ok with organizational; don't know)

Figure 4.8: below illustrates the variation of responses from the auditors. It was surprising to see the difference between the auditors' responses. Only one auditor ended up in the same category for all the questions. All the others' shifted between the different groups, i.e. from preferable opinions to standpoints less advantageous for the environment.



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

2.1 Discussion of Research results:

The first research question was:

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

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

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

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

Which consequently would increase the environmental efficiency of EMS. Accordingly, efforts to adjust the standard

ISO 14001 and the systems for its application would be advantageous from an environmental point of view.

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

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

2.2 Critical Review:

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

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

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

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

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

In general, it can be said that research in the area of design for remanufacture is becoming increasingly relevant because end-of-life considerations are becoming increasingly critical to industry. Although few companies may see DfRem as an essential requirement today, in the near future this is anticipated to change. When product take-back laws and other environmental legislation leave OEMs with vast quantities of used products to deal with, design for end-of-life will become a necessity to retain competitiveness. However, in reality, it would appear that an increase in DfRem activity in industry and an appreciation for the importance of DfRem has yet to be realized. This is a problem that requires deeper investigation. Gaining new knowledge and understanding of what conditions enable effective DfRem to take place will facilitate progress in making the task more accessible to designers. To achieve this goal, it is essential that the requirements of the OEM and the designer are taken into consideration, a feature that is missing in many of the previous developments of DfRem research. However, this does not mean that the needs of the remanufacturer may be overlooked, and therefore this investigation has begun with a pilot study of an Furthermore, in this dissertation the steps that are to be included in a generic remanufacturing process have been identified. For each of these steps, the preferable product properties have also been identified in shape of the RemPro matrix. These results were verified by the case study analysis conducted in Mumbai, Pune, Dhar and Ahmednagar. The case study also resulted in suggestions of how to improve the efficiency of the manufacturing processes.

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2.3 Future Research:

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

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

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