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ENHANCING DESIGN AND DEVELOPMENT FOR SUSTAINABLE REMANUFACTURING: EXPLORING NEW PROSPECTS

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Abstract- ***In this dissertation, five research questions were formulated to address the research objectives. Given the limitations in terms of time and resources, it was necessary to rely on overseas studies due to the low number of remanufacturing companies, particularly in Maharashtra, India. Therefore, the studies conducted were not exhaustive; however, this did not impact the research outcomes significantly. This was because the research focused on a high-level assessment of remanufacturers' perceptions of driving forces, costs, bottlenecks in the process, and similar aspects. Consequently, the essential features of the remanufacturing facilities were identified. Additionally, the conducted RPAs (Rapid Process Assessments) have contributed to the overall understanding of the analyzed remanufacturing facilities. Furthermore, the research delved more deeply into studies conducted at the remanufacturing facility operated by Whirlpool India Ltd. in Ranjangaon, Pune. These studies have, in various ways, formed the foundation for the later sections of the research. The ecological aspects of remanufacturing have been elucidated with reference to those associated with new manufacturing and material recycling.***

Keyword:- Remanufaturing, Cost, RPA, Material, Recycling

1.1 Environmental Perspectives on Remanufacturing:

The first research question, as outlined in the introductory chapter, focused on the environmental aspects of remanufacturing. In the methodology chapter, the approach for addressing this question was explained. The results section begins by presenting the findings derived from an extensive review of the literature concerning the environmental aspects related to the concept of remanufacturing. A research overview is provided, which includes the results from two case studies involving environmental analyses of remanufacturing processes for copy machines and gasoline engines, respectively (refer to Kerr, 1999, and Smith and Keoleian, 2004). Additionally, the results from the examination of Whirlpool India Limited's household appliance remanufacturing facility in Ranjangaon, Pune, are detailed.

1.1.1 Literature Study:

Examining the literature on the environmental impacts of remanufacturing, several researchers have considered remanufacturing as a highly preferable end-of-life scenario (see, for instance, Greadel and Allenby, 1996; Ryding et al., 1995; Jacobsson, 2000; and Steinhilper, 1998). It has been noted that the energy required for remanufacturing is significantly lower than recycling, provided that the item aligns with the necessary production characteristics of remanufacturing (Lund, 1996). Some of these concepts are explored in the theoretical foundation, as discussed in Section 3.2. Much of this research underscores that, with remanufacturing, the efforts invested in collecting and assembling the item and its components are saved in contrast to, for example, material recycling.

While there are limited detailed research studies on environmental remanufacturing analyses available, one notable example is the remanufacturing of Xerox copy machines, as studied by Kerr (1999). Kerr compared the remanufacturing of a conventionally designed copy machine with one specifically designed to facilitate remanufacturing. The energy savings for the Xerox model DC 265, designed for remanufacturing, were 3.1 times greater than the Xerox model 5100, and there was a 1.9-fold reduction in materials used and landfill waste.

Another study, analyzing both 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 to investigate energy savings and pollution reduction achieved in the United States through remanufacturing mid-sized automotive gasoline engines. This was compared to the production of new engines by an original equipment manufacturer. The model revealed that the remanufactured engine could be produced with 68% to 83% less energy and 73% to 87% fewer carbon dioxide (CO2) emissions. There were also significant reductions in other air emissions, including 48% to 88% less carbon monoxide (CO), 72% to 85% fewer nitrogen oxide (NOX) emissions, 71% to 84% less sulfur oxide (SOX) emissions, and 50% to 61% fewer non-methane hydrocarbon emissions. Raw material consumption was reduced by 26% to 90%, and solid waste generation decreased by 65% to 88%. An economic survey of suppliers of new and remanufactured automotive engines indicated a consumer price difference of 30% to 53% in favor of the remanufactured engine, with the greatest savings when purchased directly from the remanufacturer (Smith and Keoleian, 2004).

However, it's worth noting that a slight change in fuel efficiency could potentially reduce the environmental benefits of remanufacturing, and these issues are further discussed in the following chapter.

In addition to the analyses conducted by Kerr (1999) and Smith and Keoleian (2004), the author also supervised an independent analysis in collaboration with a colleague. The analysis was conducted by four master's students, and the results will be discussed in the next section.

1.1.2 Refurbishing Versus Recycling at Whirlpool India Limited:

The analysis involved more than an environmental comparison of two end-of-life scenarios for two household appliances. Whirlpool India Ltd. often encounters cases where household appliances become damaged or non-functional due to use or mishandling. These damaged appliances are received at various service centers across India. In the first scenario, the appliances are typically subjected to material recycling at these service centers. In the second scenario (the existing one), the appliances are transported by heavy trucks to a facility in Ranjangaon, Pune, where they are remanufactured. The methodologies employed in this analysis were LCA (Life Cycle Assessment) modeling and ABC (Activity-Based Costing), as discussed in Chapter 3. This analysis encompassed both an environmental perspective and an economic one. The products under scrutiny were a washing machine and a refrigerator (combined refrigerator/freezer).

The two different scenarios of remanufacturing and material recycling are presented in Table 8, alongside the figures for new product manufacturing (New Second). In the scenario for remanufacturing, the portion directed toward material recycling is also included. In this case, this proportion amounts to 16.7%, meaning that 83.3% of the appliances arriving at the remanufacturing facility are remanufactured and subsequently sold in the consumer market. The 16.7% of the refurbished units that are material recycled is duly accounted for and is represented within brackets in Table 6. For example, for the first refurbished product, 'non-renewable material (kg)' for the refrigerator, the figure in brackets is derived 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 O2equivale	0.2 (0.2)	0.3	14.3	1.3 (1.3)	0.05	2.5

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nts)						
Recyclable resources						
Materials (kg)	0 (12.7)	76.4	6.4	0 (7.5)	45.1	5.2
Waste						
Hazardous (kg)	0.003	-	0.23	0.002 (0.09)	0.5	2.0
General (kg)	1.1 (3.3)	13	160	1.3 (1.3)	0.1	198

The analysis reveals that for the washing machine, the remanufacturing scenario involves a significant amount of transportation, resulting in higher greenhouse gas emissions. These emissions are 12 times higher compared to the recycling scenario. On the other hand, greenhouse gas emissions are more than 60 times higher for new production in relation to remanufacturing.

In the case of the refrigerator, the use of Isobutane R600a and cyclopentane as refrigerants and blowing agents during remanufacturing presents challenges, making the recycling scenario less favorable in terms of greenhouse gas emissions.

The differences in the life cycle inventory results between a refrigerator and a washing machine (Table 6) can be primarily attributed to their weight differences and the higher emissions associated with the operation of a refrigerator. The acidifying effect of remanufacturing is smaller than that of recycling in both the refrigerator and washing machine scenarios, with heavy machinery used at recycling facilities contributing to emissions.

The release of ground-level ozone gases is minimal in both scenarios and holds little significance. Nitrogen and phosphorus compounds are the primary causes of eutrophication, and their higher levels in the remanufacturing scenario can be explained by the use of laundry detergents and detergent agents in the testing and cleaning phases of washing machines.

When interpreting the results in Table 6, it's interesting to compare remanufacturing to new production, as the end goals of these scenarios are somewhat similar. Comparing remanufactured appliances to recycled materials being incorporated into newly manufactured appliances would make the scenarios more comparable. However, this would introduce additional factors like transporting recycled materials from the original recycler to the manufacturing facility. It's important to note that previous analyses by Kerr (1999) and Smith and Keoleian (2004) focused on comparisons between remanufactured and newly manufactured products. These findings emphasize the importance of setting system boundaries to achieve meaningful results.

From an environmental perspective, remanufacturing appears to be a favorable way to achieve a functioning product. The remanufacturing process results in a functional product, while recycling only provides materials. The downside, compared to recycling, is the need for longer transports due to the limited number of refurbishment facilities in India. However, sophisticated logistics have minimized the number of transports needed. Energy consumption at the refurbishment facilities is relatively low as most of the work is done manually. The emissions and energy requirements resulting from refurbishment are significantly lower than those for entirely new production. For example, the energy needed to produce a new refrigerator is 50 times greater than that needed for refurbishment, and the energy used for a new washing machine is 30 times more than for refurbishment. Material resource consumption is much higher when producing entirely new products, which is a concern as non-renewable resources are becoming scarcer.

The study aligns with Whirlpool India Ltd.'s own evaluation, which also shows that emissions from refurbishing refrigerators are lower than those generated in the recycling scenario. Furthermore, Whirlpool India Ltd.'s assessment had smaller system boundaries, making this comparison more robust. The energy saved by Whirlpool India Ltd. when remanufacturing products in Ranjangaon, Pune, instead of manufacturing new ones was equivalent to powering 250 households annually.

In addition to the ecological calculations, an economic analysis of the scenarios was conducted. It is evident that the refurbishment scenario incurs higher costs than the recycling scenario. This is because refurbishment is a value-added process and requires substantial efforts to enhance the value of an old household appliance. Recycling, on the other hand, adds limited value to the product, mainly involving shredding and sorting materials for recycling. However, refurbishment generates income and a positive environmental image for Whirlpool India Ltd. The refurbished products are sold to retailers, and the income from retailers can cover the

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costs incurred during refurbishment. The overhead costs in refurbishment are relatively high (around 70%) due to the need for storage areas for spare parts and products waiting for parts not currently in stock. Despite these expenditures, the refurbishment process for household appliances was found to be profitable.

In the recycling scenario, the costs were analyzed at a higher level than in the existing refurbishment scenario. A comprehensive working system for systematic recycling is not yet in place, so the recycling scenario was assessed through cost estimation. It was found that recycling costs were associated with transportation, collection, and recycling of the appliances. The main economic difference between refurbishment and recycling lies in the potential income generated by the refurbished products, which have substantial economic value after the process. Furthermore, refurbishment adds value to the product, whereas recycling typically does not. In the recycling process, products are shredded and recycled into different raw materials that can be reused in various value-added processes.

In summary, the results of the analyses conducted indicate that remanufacturing is generally preferable to other end-of-life scenarios or entirely new production from an environmental perspective, given that the remanufacturing process results in functional products. These results align with the end-of-life priority lists outlined by Graedel and Allenby (1996) and Ryding et al. (1995). Furthermore, the refurbishment of household appliances in the Ranjangaon, Pune facility was found to be profitable, consistent with the study conducted by Smith and Keoleian (2004).

1.2 The Generic Remanufacturing Process:

The second research question focuses on identifying the steps in a generic remanufacturing process. In most cases, similar to the previous research question, this inquiry is addressed by reviewing the work of other researchers in the field. This is explained in more detail in the methodology chapter.

In the theoretical foundation, various types of remanufacturing businesses are described (see Section 3.2.2). Depending on the type of remanufacturing exercised, the sequence of executing the remanufacturing steps may vary. From the author's experience during site visits, remanufacturing companies choose different sequences for performing the remanufacturing steps. For example, the cores could either be disassembled, followed by inspection (e.g., error detection), or inspection could be the initial step, followed by disassembly. In research, the remanufacturing process is often described with the inspection step preceding the cleaning and disassembling steps (see, for example, Steinhilper, 1998; Smith and Keoleian, 2004). This sequence is not always efficient; however, if the assessment has significant errors, it may be useless to remanufacture the item. In practice, a preliminary inspection for major defects is usually performed as part of the initial sorting when items arrive at the remanufacturing service facility. Nevertheless, detailed inspections are easier to conduct once the item has been cleaned. Therefore, every remanufacturing process is unique, and it is necessary to choose a strategy for efficient remanufacturing 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 specific type of product, remanufacturing volume, and other factors.

An example of how appliances are remanufactured in the remanufacturing facility in Ranjangaon, Pune, is shown in Figure 4.1.

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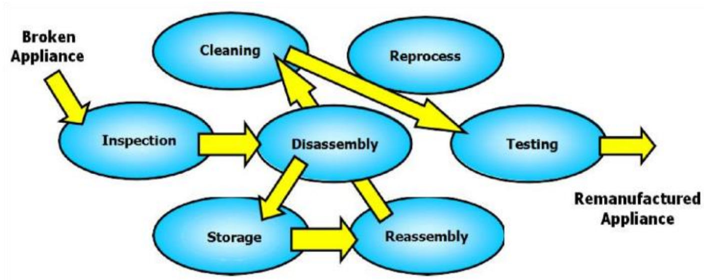

Figure: A step-by-step illustration of household appliance remanufacturing at Whirlpool India Pvt. Ltd., Ranjangaon, Pune. In this example, the appliances are first inspected to locate any problems. Secondly, damaged parts are disassembled, and the remaining components of the appliance are stored. The product is then reassembled with new spare parts or components obtained from other products. Afterward, it is thoroughly cleaned and tested to ensure it functions properly. The appliance is now considered remanufactured and ready to be shipped to a retailer for resale. Please note that the repair step is omitted in this example since damaged parts are replaced with new ones or spare components.

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Another example from 'Cummins Generator Technologies India Pvt. Ltd,' in Ahmednagar, is shown in Figure 4.2.

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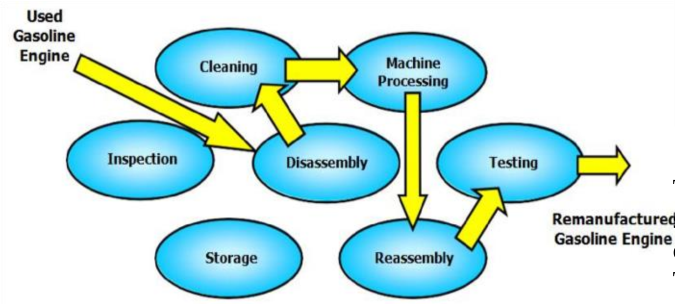
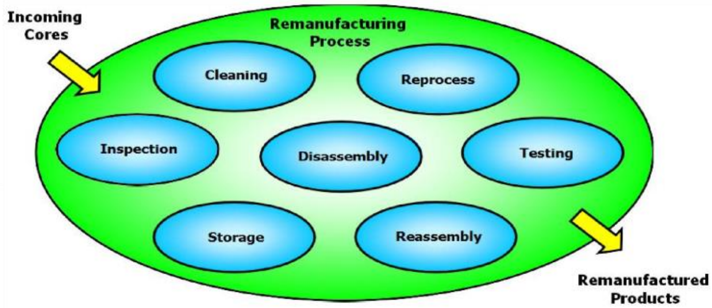


Fig 4.2: A step sequence of gasoline remanufacturing at 'Cummins Generator Technologies India Pvt.Ltd. Ahmednagar.

In the case of 'Cummins Generator Technologies India Pvt. Ltd', Ahmednagar, the straightforward process of remanufacturing begins with the disassembly of the engine core into its individual components. Following this, it proceeds through a cleaning process where dirt and debris are removed. Subsequently, several parts go through a machining process in which the engine is reprocessed to desired dimensions, and critical sealings and surfaces are treated. Next, the assembly step follows, during which the engine's components are reassembled. Finally, the engines undergo compression testing using air, and leak testing is performed to check for water cavities. These different cases represent various approaches to organizing the remanufacturing steps. In these remanufacturing processes, internal transportation and packaging of the products are not considered as remanufacturing process steps.

In Paper, Figure Properties Essential for Remanufacturing by Sundin E. (2001), a generic remanufacturing process is described based on the results of other researchers' work and by examining Tornado India Ltd. Ranjangaon, Pune. To verify and further refine the generic remanufacturing process, six remanufacturing case studies were conducted (also related to research question 4). Combining the literature review and the remanufacturing case studies, we obtain the following representation of a generic remanufacturing process shown in Figure 4.3.



The remanufacturing process typically involves a step called reprocess, which encompasses various operations to restore the product to a usable state. This step can vary significantly depending on the type of product being remanufactured. The specific sequence of steps in a remanufacturing process can vary as well. In many generic remanufacturing processes, the possible steps are laid out without a predefined order. The order of these steps is determined by several factors, including product design, the operating environment, production volume, and other relevant considerations.

The findings related to the order and organization of remanufacturing processes, as well as the factors influencing these processes, are further discussed in Sundin's paper titled Product Properties Essential for Remanufacturing and an Economic and Technical Analysis of a Household Appliance Remanufacturing Process.

1.3 Preferable manufacturing product properties:

In the process of identifying the generic remanufacturing steps, it posed a challenge to determine the preferable attribute properties for each step. To address the third research question mentioned in Section 1.3, previous research and my own research conducted in Linköping were combined. The research related to this question is primarily described in the papers Enhanced Design Facilitating Remanufacturing of Household Appliances - A case study, An Economical and Technical Review of a Household Appliance Remanufacturing Process, and Refurbish or Recycle Household Appliances? An Ecological and Economic analysis of Electrolux in Sweden, authored by Household Appliances - A case interpret, Sundin E. (2001) and Tyskeng S. (2003), respectively.

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About the attribute properties from the steps in the generic remanufacturing process (Figure 4.3), they can be condensed into the following form (see Figure 4.4 below) of remanufacturing attribute 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 shown above illustrates the preferred attribute properties for the different steps in the remanufacturing process. The RemPro matrix can further be used as a design tool. Using this tool, the designer can easily see which properties each step requires, depending on the part being designed. For example, during the cleaning phase, the attribute easy to access and resist the cleaning solutions might be of particular interest and emphasized. During inspection, on the other hand, it is crucial to verify what the condition of the part is. Furthermore, for the inspection step, it might be essential for parts to be easy to identify and assay-friendly.

It's important to note that having the entire remanufacturing process in mind when designing a part is crucial. Designing a single step without considering the others can lead to difficulties or increased costs in subsequent steps. One crucial aspect to remember throughout the essential effort in remanufacture is reuse. If a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly becomes a significant factor.

To conclude, this section has highlighted that there are various attribute properties to consider when designing for remanufacturing. Factors like part type, volume, remanufacturing system, etc., need to be considered since they are essential when setting the remanufacturing sequence and determining which properties to prioritize.

Since the remanufacturing process involves multiple steps, there are some essential properties that parts need to have to be remanufactured efficiently. Through a review of literature on remanufacturing processes and analyzing the Tornado India Ltd. Ranjangaon, Pune facility, it was possible to determine which kinds of attribute properties are essential for different remanufacturing steps. The following key attributes are among the most significant:

Ease of Access: Making components or parts easy to access is crucial for efficient remanufacturing.

Ease of Identification: Items should be easily identifiable during the remanufacturing process.

Wear Resistance and Ease of Handling: Products or components should resist wear and be easy to handle during remanufacturing.

These properties provide answers to the third research question outlined in Section 1.3

1.4 Results from remanufacturing case studies:

To address the fourth research question, a case study involving six different remanufacturing companies was conducted. The case study methodology is detailed in the research methodology chapter, including methods such as the rapid plant assessment (RPA) approach. The case study reports for each company are included in Appendix A. In this section, I will briefly describe the results from the individual case studies at the remanufacturing facilities. The results from the remanufacturing companies will be presented in the following order:

- 'Vishesh International'
- '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, which adheres to the case study methodology as described by Yin (1994). In this cross-case analysis, the companies in the case study are compared, and general results and insights are provided. It involves looking for

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common themes, patterns, or variations across the different cases to draw broader conclusions.

The cross-case analysis allows for a comprehensive understanding of the remanufacturing processes, strategies, and challenges across multiple companies, highlighting both similarities and differences in their approaches. It provides a more holistic view of the research findings and can help identify best practices, key factors, or potential areas for improvement in the field of remanufacturing.

1.4.1 Vishesh International:

The first case study was conducted at 'Vishesh International,' a small remanufacturer of toner cartridges located in Malad, Mumbai. This family-run business operates with just one remanufacturing facility and employs 17 people. Their primary motivation for entering the business was to establish a brand identity, and a secondary motivation was to contribute to reducing the accumulation of waste in landfills. The facility primarily focuses on remanufacturing toner cartridges, primarily from laser printers, photocopiers, and fax machines. They reprocess only the cartridges and some other components used in printers. Currently, they remanufacture approximately 1300 cartridges per month, with a target to increase this number to 2000. The remanufacturing of cartridges follows a specific step sequence:

1. Receive empty cartridges from customers.
2. Disassemble the cartridges.
3. Clean the components.
4. Separate the parts for further processing.
5. Refill the cartridges with toner.
6. Reassemble the cartridges.
7. Test the remanufactured cartridges for quality.
8. Package the cartridges for sale.

Rapid Plan Assessment

Based on the questionnaire with 20 questions in the RPA-sheet, where 8 questions were answered yes, a lean score of 55 was calculated. This score indicates a need for improvement in material flows within the process and better utilization of space. Additionally, it suggests that inventory levels and work-in-progress should be considered. Improving the integration of the supply chain can significantly impact these areas and lead to process optimization.

Company Analysis

The organization's storage areas are quite extensive but need to be reduced in size to save costs. Improved knowledge of which and how many different cartridges are entering the facility could optimize the process by adapting storage for incoming cartridges instead of having excessive storage for various cartridge types. The current storage arrangements are space-intensive, both for empty cartridges and new spare parts. Additionally, there seems to be excess inventory in storage holdings, which could be managed more efficiently.

One significant challenge in this operation is that the original equipment manufacturer (OEM) competes in the same market by offering new cartridges. This competition affects the design of cartridges negatively from a remanufacturing perspective. If OEMs had their own remanufacturing business, the cartridges would likely have been designed with remanufacturing in mind. However, when independent remanufacturers remanufacture cartridges for the same market, the cartridges are optimized for new manufacturing. As a result, customers end up paying more for remanufactured cartridges than necessary.

Given the relatively low volumes (16,000 cartridges per year) and a modest number of product variants (160), it is crucial to maintain a flexible process. This can be achieved through the use of skilled operators who can perform every step in the remanufacturing process. Cleaning and toner refilling are the steps that take the most time in the process. The company could consider investing in additional equipment, such as a filling machine, to improve at least the filling step. Installing a second testing machine could also help speed up the process.

1.4.2 Go Print

The second case study was conducted at 'Go Print,' a large remanufacturer of toner cartridges located in Santacruz, Mumbai. The primary motivation for starting this business was economic. 'Go Print' operates as an independent entity and does not belong to a larger corporate group. The facility in Mumbai, Maharashtra, is unique in its kind. During prosperous times, the company employs around 400 people. 'Go Print' holds an ISO9002 certificate, which aids in structuring the quality management system at the facility. While they do not use ISO14001, they are environmentally conscious and promote their business as being beneficial for the environment in customer brochures.

At 'Go Print,' toner cartridges are remanufactured, mainly sourced from laser printers, photocopiers, and fax machines. Currently, they remanufacture around 210,000 cartridges annually. The remanufacturing process for cartridges at 'Go Print' involves the following steps:

1. Receiving and sorting the empty cartridges.
2. Analyzing the cartridges.
3. Disassembling the cartridges.
4. Reassembling and refilling toner.
5. Post-testing the cartridges.
6. Tagging and bagging.
7. Packaging.

Rapid Plan Assessment

The questionnaire filled out during the ramp-up assessment indicates that 'Go Print' received 11 yes responses, and the connected score was 65. This score primarily addresses issues related to material flows, space utilization, and the means of material movement, all of which are considered below average. This suggests that 'Go Print' should focus on addressing these issues and improving their remanufacturing process. While there may be other issues to consider, these mentioned areas should be their primary concern.

Company Analysis

'Go Print' seems to have relatively high product volumes, making it possible to implement line-based remanufacturing processes. Currently, the process is largely station-based, and there is an opportunity to streamline the process by situating the remanufacturing steps closer together, which would reduce unnecessary transports. In particular, steps like disassembly, reassembly, and testing could be more efficiently handled with parallel flows for different product types, likely improving process efficiency.

Operators currently need to move between the bench for disassembly/reassembly and the testing area before delivering the cartridge to the next step. Some parts of the process are automated, which helps speed up the workflow. However, since there is only one machine performing the analysis before disassembly, it might be beneficial for 'Go Print' to consider investing in a second testing machine.

Most of the process is manual, providing flexibility for the various product types being remanufactured. If the disassembly/reassembly steps are redesigned, 'Go Print' should also consider improving working conditions in the facility by addressing issues like noise levels and allowing operators to shift positions in their lines.

Overall, reorganizing the remanufacturing steps, reducing the number of cartridges in storage, and making the process more efficient and lean could significantly benefit 'Go Print.'

1.4.3 Cummins Generator Technologies India Pvt.Ltd.

The third case study was conducted at Cummins Generator Technologies India Pvt. Ltd in Ahmednagar, Maharashtra. This company is a major remanufacturer of both automotive and non-automotive gasoline engines. While their primary objective is profit generation, they achieve this through remanufacturing. They also consider the ability of the original engine manufacturing plant to provide capacity, and in such cases, they utilize their existing equipment for new manufacturing, while Cummins Generator Technologies India Pvt. Ltd focuses on providing capacity through remanufacturing operations.

This business approach, which involves part recycling (remanufacturing), is economically advantageous. Cummins Generator Technologies India Pvt. Ltd employs over 2000 people worldwide, with 180-200 dedicated to non-Cummins products at the plant in question.

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The remanufacturing process at Cummins Generator Technologies India Pvt. Ltd involves the following steps:

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

Rapid Plan Assesment

Cummins Generator Technologies India Pvt. Ltd received a high score in the RPA assessment, particularly in the categories of 'capacity to manage flexibility and variability' and 'Quality System Deployment.' This achievement is attributed to the company's extensive experience and stringent quality standards. However, the company scored poorly in the areas of 'Product flow, space use, and material motion manner' and 'Inventory & WIP Levels,' receiving a total of 57 points in these categories.

Company Analysis

Cummins Generator Technologies India Pvt. Ltd has been involved in remanufacturing for a significant period of 18 years. It is an example of a remanufacturing business that began its operations prior to the establishment of the remanufacturing industry push initiated after the Scrap Evaluation in Maharashtra. The company is certified with a strong commitment to quality and environmental standards, particularly in its remanufacturing processes, where environmental concerns related to packaging, chemical spills, and processes are carefully considered.

The material flows within the company are well-organized, as the process steps in the facility are laid out in a structured sequence. Storage levels are minimal, especially as the initial part of the process (disassembly-cleaning-machining) is performed separately from the latter part (assembly-test-packaging). The process in the early stages of the facility is more station-based than the latter section. Additionally, the machining process involves some parallel flows with multiple assembly lines, which helps prevent potential bottlenecks in the process.

Cummins Generator Technologies India Pvt. Ltd maintains a strong relationship with manufacturers, as they serve as both suppliers and customers to these manufacturers. The remanufacturing process at Cummins is closely aligned with the manufacturers' requirements.

While the overall process is well-organized, there are areas for potential improvement. The cleaning step could be enhanced since it is labor-intensive and time-consuming. Additionally, the machining step involves a considerable amount of consumable supplies and substantial investment, making it a costly part of the process. Machining and assembly are steps that still require significant energy use, which could potentially be reduced.

1.4.7 Cross Case Analysis

In this section, the companies are compared, and general results are described. An interesting finding in the case studies was that the reasons for remanufacturing varied among these companies. The primary driving forces behind remanufacturing are shown through a few examples. Toner cartridge remanufacturers in India are primarily motivated by market demand. In Mumbai, where there is a steady supply of discarded stock, legislative incentives encourage remanufacturers by requiring them to manage their manufactured products as part of extended producer responsibility regulations. Additionally, remanufacturers/recyclers receive end-of-use products. In South and Western India, the strong driving force for remanufacturing single-use cameras is of environmental origin. This is due to the fact that used single-use cameras are returned to retailers and need to be managed properly. It is also seen as a way to improve the environmental image of the company. Many of these companies derive economic benefits directly or indirectly from their remanufacturing businesses. Although it is interesting to compare these companies, some general conclusions can be drawn.

- The uncertainty regarding the quantity and timing of cores arriving at the remanufacturing facilities is a common challenge for many of the analyzed companies, making the planning of remanufacturing more complex.

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- Remanufacturing companies often have a high amount of cores, spare parts, or half-finished products in storage, awaiting customers or spare parts, which ties up space and capital within the process.

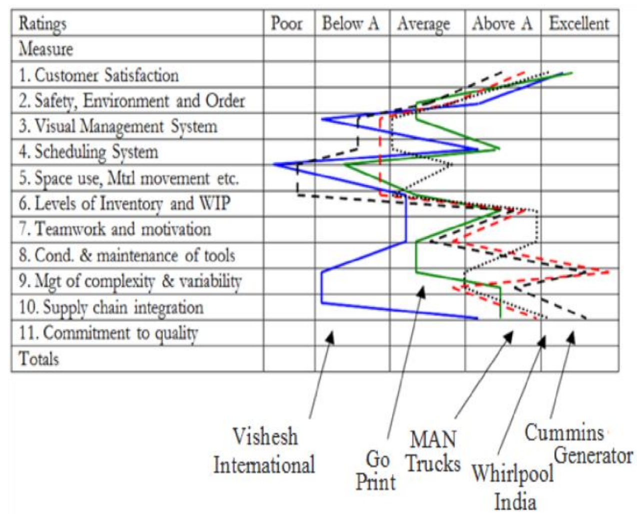
- Cleaning and reprocessing (repair) are crucial steps in three of the companies ('Vishesh International,' 'Cummins Generator Technologies India Pvt. Ltd,' and Whirlpool India Ltd).

- Inspection is a crucial step in two of the companies ('Go Print' and Signal Circuits Pvt. Ltd).

Table 7 provides an overview of the analyzed companies, and the overall RPA scores from the RPA scoring sheets range from 55 to 57, with the exception of '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**	**-**

The conclusion that can be drawn from Table 4.2 is limited, mainly indicating that one company appears to be more efficient from a lean perspective than the others. This discrepancy might be attributed to the fact that 'Go Print' holds an ISO9001 certificate and deals with a high volume of remanufactured products, which makes it easier to achieve efficiency. Additionally, the types of cartridges being remanufactured by this company are rather similar. Instead of solely relying on the aggregated RPA scores, it is, at least in this study, more insightful to compare the RPA scoring sheets presented in Table 4.3 below.



In general, the analysis indicates some common trends and specific characteristics among the remanufacturing firms, despite there being only five companies analyzed in this case study. The RPA scores reveal areas of strength and areas that require improvement in pursuit of greater lean and operational efficiency. Here are some key takeaways:

Common Challenges Across Branches:
Low scores on measures 3, 5, and 6, representing Visual Management Deployment, Product Flow, Space Use, Material Movements, Inventory, and WIP Levels. This suggests that these are areas where all companies have room for improvement.

Common Strengths Across Branches:
High scores on measures 1, 7, 9, and 11, representing Customer Satisfaction, People Teamwork, Skill Level, Motivation, Ability to Manage Complexity and Variability, and Quality System Deployment. This indicates that the companies excel in customer satisfaction, teamwork, quality management, and their ability to manage complexity.

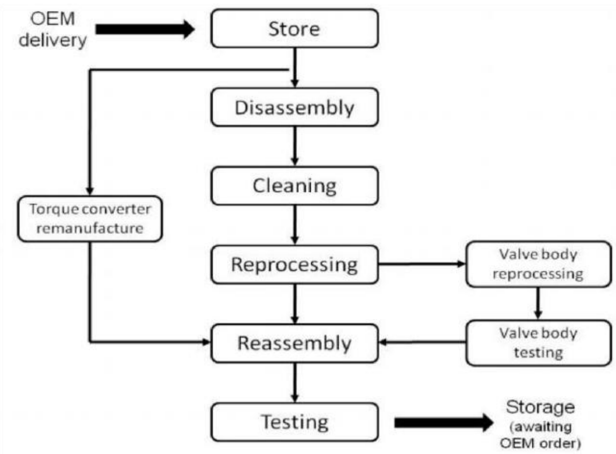
Branch-Specific Observations:

Toner Cartridge remanufacturers ('Vishesh International' and 'Go Print') scored higher than others on measure 4 (Scheduling System) but lower on measure 9 (Ability to manage complexity and variability).
Engine remanufacturers performed well on measure 9 (Ability to Manage Complexity and Variability).
Whirlpool India Ltd. excelled in measures 5 and 8, which represent Product Flow, Space Use, Material Movements, Equipment, and Tooling State and Maintenance.

Effect of Remanufacturing Volumes:
The data suggests that higher remanufacturing volumes generally result in higher overall scores, as seen in the graphs for both engine and toner cartridge remanufacturers.
In summary, the case study highlights that there are some common areas where remanufacturing firms need to improve to achieve greater lean and operational effectiveness. While the overall RPA ratings provide some insight, a more detailed examination of the RPA scoring sheets reveals valuable specific results. Although there are only five remanufacturing companies analyzed, the graphs within the same branch show similar patterns, suggesting common challenges and opportunities for improvement.

1.5 Design Documents

One of the key barriers to effective remanufacturing was the lack of access to design information. The remanufacturer did not have access to the original design documents, even though they had a direct relationship with the original equipment manufacturer (OEM). The primary reason for this lack of access is the protection of intellectual property (IP). If an OEM were to share their critical design information with their contractor, there could be potential security risks from the competitors of the OEM, who might also use the same contractor for remanufacturing. However, this IP protection issue means that cores are remanufactured based on reverse engineering, a complex and time-consuming process that may not be 100% accurate.



Design Problems: Durability

One key design-related problem the remanufacturer faced was related to durability. Durability is a key feature in Design for Remanufacturing (DfRem) guidelines, yet the organization had been experiencing a significant drop in durability over the previous few years. Lighter, less durable materials were increasingly being selected in automotive design to reduce the vehicle's weight and, in turn, decrease fuel consumption, which is a clear environmental benefit. However, these materials wore out at a much faster rate than previous designs. When sent for remanufacturing, they had to be discarded more frequently, or at least they were more challenging and expensive to restore to a like-new condition. This was costly for customers and undesirable for OEMs as they were paying for remanufacturing services. This situation is a clear example of the conflicts within DfRem: the tension between improved environmental performance and retained remanufacturability. Furthermore, the increasing use of plastics in automotive products presented a similar problem. These materials were cheaper to produce but impossible to remanufacture and had to be replaced, making the remanufacturing process more costly.

OEM Feedback

While the remanufacturer would regularly provide 'diagnostic' feedback related to specific product failures and faults, they were unaccustomed to providing Design for Remanufacturing (DfRem) feedback, which involves design optimization, to the OEM. Overall, communication with the OEMs was considered a complex, slow, and generally

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unrewarding procedure. One reason given for these challenges was the globalization of the company's clients: the management responsible for making design changes may be located in another country. It's also possible that being accustomed to certain design norms and working conditions over time means that personnel at a remanufacturing plant may be unable to recognize product design-related issues.

Confab

The organization aims to integrate Design for Remanufacturing (DfRem) into the design process by first reviewing the literature and conducting a pilot study to identify the challenges and issues that could affect this integration. Preliminary findings from an automotive contract remanufacturer have highlighted some critical concerns.

One significant criticism of current DfRem guidance is its lack of lifecycle awareness. The study revealed that the used products analyzed had been designed for optimal environmental performance, which, ironically, hindered effective remanufacturing. This suggests that remanufacturing concerns are not a primary focus in new product development.

A lack of design feedback is identified as a major issue affecting DfRem's position in the design process. Designers may not consider remanufacturing issues simply because they are not aware of them. Previous research has suggested that designers may lack the necessary knowledge for effective DfRem, and feedback from remanufacturers may be crucial in raising awareness. The reasons for this lack of communication between OEMs and remanufacturers are unclear but could be due to OEMs not listening, remanufacturers being accustomed to certain issues, or a combination of both.

The pilot study observed an automotive remanufacturer working under contract with automotive OEMs. As most previous discussions around DfRem have focused on OEM remanufacturers, the specific issues of this relationship remain underexplored. Preliminary findings suggest that there is a lack of trust between OEMs and contract remanufacturers, hindering the flow of design information and discussion. If this communication restriction is unavoidable, it may imply that successful DfRem implementation occurs primarily when the OEM is directly involved in remanufacturing.

1.6 Integration of DfRem aspects into EMSs

The fifth and final research question explores how aspects of Design for Remanufacturing (DfRem) can be better integrated into a company's Environmental Management Systems (EMS). To address this research question, a broader scope was taken, considering various aspects of Design for Environment (DfE), not just DfRem. The results of this investigation are briefly described in this section, with more detailed information available in papers titled Products in Environmental Management Systems: Drivers, Barriers, and Experiences and Products in Environmental Management Systems: the Role of Auditors, authored by Ammenberg J. & Sundin E. in 2004, respectively.

The research project began with a literature review to understand the experiences of integrating DfE into EMS, sometimes referred to as result-oriented Environmental Management Systems (POEMS). The literature review highlighted the crucial role of external auditors in the integration of DfE. Consequently, the study delved deeper into the role of external auditors in integrating DfE and EMS.

1.6.1 Experiences found from the literature study

A brief examination of various Result-Oriented Environmental Management Systems (POEMS) models, such as those presented by Cramer and Alders (1999), Karlsson (2001), Klinkers et al. (1999), Rocha and Brezet (1999), and Rocha and Silvester (2001), reveals that they share a significant level of similarity at a general level. However, they use different terminology, and the categorization of elements within the different stages of the PDCA cycle may vary. Overall, based on the references cited above and the authors' own expertise, the general steps in most product-related parts of a POEMS model can be summarized as the PDCA cycle, as depicted in Figure 4.6. The described process primarily focuses on the initial implementation of a POEMS, which can be undertaken by companies with or without an existing EMS or other management systems.

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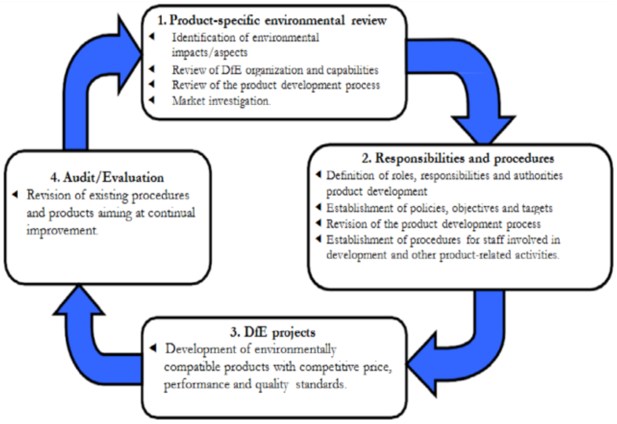
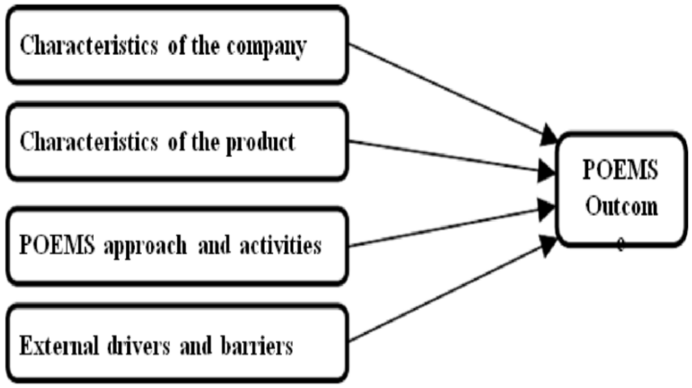


The investigation revealed that research findings on the outcomes of Result-Oriented Environmental Management Systems (POEMS) are scarce, making it challenging to draw general conclusions about the effects of POEMS. Based on case studies, it is known that POEMS projects driven and supported by consultants, for example, may yield positive results.

Studies on traditional Environmental Management Systems (EMS) show that researchers have differing opinions regarding the extent to which EMS encompasses and influences product issues. Some research results indicate that Design for Environment (DfE) and EMS activities are effectively integrated, while others suggest that the link between DfE and EMS is weak.

The extent to which companies are willing and able to integrate DfE aspects into their management systems depends on various factors. It is 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 the literature as important for either of these concepts have been gathered and categorized into four different levels, as shown in Figure 4.7. The elements of each level all affect the extent to which DfE and EMS are integrated and the outcomes of such integration.



A theoretical and environmental exploration reveals that there are compelling incentives to integrate Design for Environment (DfE) principles into standardized Environmental Management Systems (EMS). DfE integration can enrich EMS by providing a lifecycle perspective, aiding organizations in identifying the most significant material and energy flows to focus on. From a societal and environmental perspective, many environmental issues related to specific sites (point sources) have already been largely resolved or significantly reduced. Instead, environmental stress resulting from consumer markets, such as diffuse emissions, remains a significant concern. Therefore, from an environmental standpoint, having an EMS that covers a broader scope is preferable and makes EMS a more useful tool in the pursuit of sustainable development.

On an organizational level, the integration of DfE and EMS could foster better relations with stakeholders, particularly those actively involved in the organization's operations. This integration could also enhance internal cooperation among members of different departments. Simultaneously, EMS can help make DfE efforts more permanent, leading to consistent and systematic DfE activities.

Based on the information presented, it appears appropriate to envision the desired integration as consisting of two main components. The first component pertains to integrating environmental aspects into the product development process, while the second component involves integrating the product development process into the organization's management system. External environmental auditors and environmental consultants play significant roles in this context, as they can act as both drivers and barriers to the integration of standardized EMS and DfE concepts. However, existing EMS standards

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need to be adjusted as well to achieve improvements in environmental performance. The literature review was complemented by the examination of the role of external auditors, the results of which are described in the following paragraphs.

1.6.2 Experiences from external EMS Auditors

The critical environmental aspects are the pivotal elements that drive the progress of an Environmental Management System (EMS). Consequently, to a large extent, the environmental effectiveness of these systems depends on how responsibility and consideration-related aspects are classified as significant. The responses regarding this issue indicated discrepancies concerning issues related to the entire life cycle, which are sometimes regarded as substantial aspects and sometimes not considered environmental aspects at all. This means that insufficient attention is often given to product characteristics, such as resource demands in the use phase, end-of-life phase impacts, recyclability, and more. However, aspects related to resource use and energy appear to be considered as environmental aspects, which is positive. For instance, a few auditors emphasized the need for companies to improve their purchasing procedures and the use of chemicals. Nevertheless, some answers also revealed that the requirements imposed on suppliers sometimes tend to be very weak, and this appears to be even worse concerning customer requirements. One significant issue is the companies' ability to influence the life-cycle phases after manufacturing. To ensure that the most crucial aspects of materials and energy are included in the EMS, the primary requirements or at least their interpretation must be altered to account for issues that are rarely considered environmental aspects, especially for many companies.

The assessment of environmental aspects is a more delicate question. It is concerning that product-related aspects are rarely considered significant, and some companies are hesitant to assess product aspects as significant. Generally speaking, many important resource flows are clearly connected to products, which is why, according to existing standard formulations, they should be regarded as significant aspects. The problem is that the standard does not and probably cannot define the scope of an EMS and guide on how to weigh aspects that exist along the life cycle.

Regarding the complete EMS, an absolute majority of auditors stated that they are focused on a specific facility. This means that a dominant part of the EMS activities and procedures applies to the certified site. To what extent these activities and procedures are based on a life-cycle perspective and complemented with EMS parts 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 complex tools, difficulties in receiving useful information, and a lack of resources in terms of staff and competence. An important comment was that legal requirements steer companies towards a site-oriented perspective. It is unfortunate that many EMSs seem to have a narrow scope. It would be advantageous if EMS could cover a broader perspective, as legal requirements and authority control largely focus on facilities. Seen from a societal environmental perspective, many pollution problems related to specific sites (point sources) have been resolved or significantly reduced. Instead, environmental impact caused by the consumer market, e.g., in the form of diffuse emissions, stands out as significant. Consequently, from an environmental standpoint, having an EMS that covers a broader scope is preferable and makes EMS a more useful tool when striving for sustainable development.

The auditors' discussions have provided them with significant opportunities to strengthen the link between Design for Environment (DfE) and Management Systems (MS) over the years. While a few auditors requested more stringent purchase and sale formulas, others sought clarifications rather than stricter requirements. The issue of the extent to which auditors are permitted to act as consultants is a hot topic when assessing these impressions and comments. Various interviewees spontaneously mentioned that they tend to suggest that they are not in direct competition.

To strengthen the connection between DfE and EMS, customer demands appear to be of crucial importance. This includes both consumers and business customers. Large multinational companies were mentioned as important players in this field, as they have a significant influence on smaller suppliers. Other areas mentioned include improved legislation and increased competence and knowledge.

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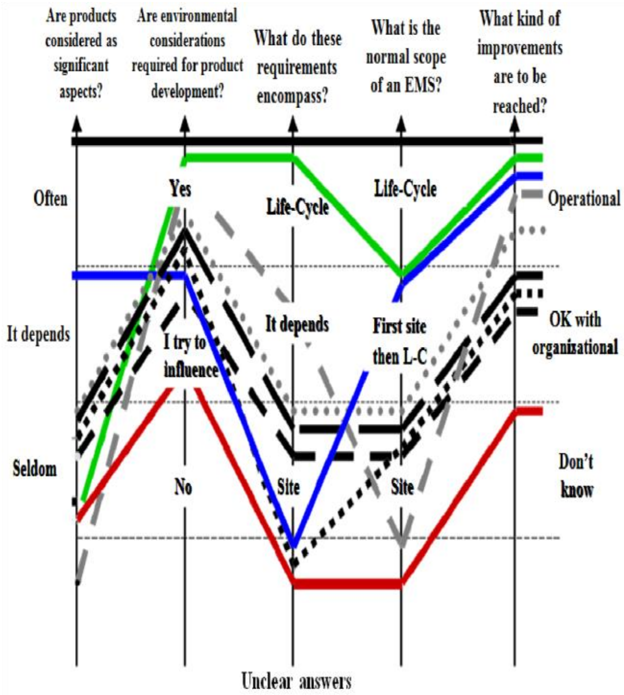
1.6.3 Comparison of Auditors

A simple test was conducted to demonstrate how auditors' views differ and to verify how some of them almost always impose tougher requirements than others. The answers were compared and classified into one of three categories for five important areas, depending on which is more preferable from an environmental standpoint. The five concerned areas (the three classes are within parentheses):

- 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 yielding of improvements are required to be reached

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



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

2.1 Discussion of Research results

The first research question was:

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

Environmental researchers often suggest that end-of-life scenarios, with remanufacturing as one of the most preferable alternatives, offer significant environmental benefits. Remanufacturing retains the geometric shape of the product and preserves its economic value. When products are designed with remanufacturing in mind, even more environmental benefits can be achieved. Comparing remanufacturing to material recycling or replacing the product with a newly manufactured one, several environmental analyses indicate that remanufacturing is generally the environmentally preferable option concerning material use.

However, the preferred end-of-life scenario can vary depending on the specific case and the remanufacturing context, such as product type and available technology. The environmental performance of remanufacturing is influenced by factors like the energy intensity during the product's use phase. Even when remanufacturing may be less beneficial for products with high-energy intensity during use, the benefits it provides should not be ignored. From a resource efficiency standpoint, remanufacturing can be advantageous for products with different levels of energy intensity during the use phase.

These issues were also discussed by Smith and Keoleian (2004). Their study explored the importance of real equivalency between new and remanufactured engines. Their analysis revealed that even a one percent improvement in fuel efficiency for an automobile powered by a remanufactured engine could have a significant impact on the lifecycle energy savings, while a one percent decrease in efficiency could negate the benefits of the remanufactured engine. Therefore, the technology of the new product, compared to the remanufactured product, can significantly affect the environmental impact.

In order to avoid these technological constraints on remanufacturing, products must be designed to be easily upgraded to incorporate the latest technology.

From a material resource perspective, this research has shown that remanufacturing is a preferable option compared to manufacturing newly. However, from a global environmental perspective, it is not entirely clear-cut. Remanufacturing is a preferable option as it may lead to fewer greenhouse gas emissions, especially if it involves using various modes of transportation that have lower environmental impacts for the remanufacturing process. For the integration of Design for Environment (DfE) in Environmental Management Systems (EMS), the knowledge of DfE and product development among EMS practitioners is crucial. During interviews with external auditors, it was found that EMS practitioners in companies often lack the necessary knowledge. External auditors are responsible for auditing compliance with EMS standards, not for providing consulting services to manufacturing companies. However, in some cases, auditors do impart DfE knowledge to manufacturers, and they play a pivotal role in promoting the integration of DfE and EMS.

To include remanufacturing aspects in a manufacturing company's environmental management, these aspects need to be recognized as important environmental aspects within the company. This recognition will lead to services and practices that address remanufacturing aspects. Additionally, the concept of remanufacturing should be better disseminated among companies and external auditors to spread knowledge and set remanufacturing goals. If external auditors emphasize a life-cycle perspective in their audits, manufacturers are more likely to incorporate remanufacturing aspects into their environmental management systems.

2.3 Critical Review

In this dissertation, five research questions were formulated to address the research objectives. Given the limited time and resources, the researcher had to rely on overseas studies due to the limited number of remanufacturing companies, especially in Maharashtra, India. While these studies were not conducted in-depth, they did not significantly impact the research results. The research primarily focused on a high-level analysis of remanufacturers' opinions on driving forces, barriers, and bottlenecks in the process. The general characteristics of remanufacturing facilities were identified.

Furthermore, the research included Reverse Process Analyses (RPAs) to complement the overall understanding of the analyzed remanufacturing facilities. The study also delved into in-depth investigations of the remanufacturing facility operated by Spin India Ltd. in Ranjangaon, Pune, with studies of Charybdis India Ltd. serving as a basis for comparison.

The environmental aspects of remanufacturing were compared to those generated by new manufacturing and material recycling. It was concluded that determining whether remanufacturing is environmentally preferable depends on which environmental aspects are considered most important. From a material resource perspective, remanufacturing was found to be preferable for at least three different kinds of products, aligning with previous research results.

In this dissertation, the steps involved in a generic remanufacturing process were identified, and preferable product properties for each step were outlined using the RemPro matrix. These results were verified through case study analyses conducted in Mumbai, Pune, Dhar, and Ahmednagar. The case studies also led to suggestions on how to enhance the efficiency of manufacturing processes.

The dissertation also explored how design for remanufacturing aspects could be better integrated into the environmental management systems of manufacturing companies.

The research primarily focused on Whirlpool India Ltd. Ranjangaon, Pune, during the first two years, with later modifications and verifications based on other researchers' results and overseas case study analyses. Addressing the research questions fulfilled the research objectives, as the dissertation described how products can be designed to facilitate the remanufacturing process and how existing remanufacturing processes can be made more efficient.

In summary, research in the area of design for remanufacturing is gaining relevance as end-of-life considerations become increasingly critical. While few companies may not yet view DfRem as an essential requirement, it is anticipated that this perception will change in the near future. When product take-back laws and environmental legislation leave Original Equipment Manufacturers (OEMs) with substantial quantities of used products to manage, designing for end-of-life will become a necessity to remain competitive. However, in reality, an increase in DfRem activity in the industry and a broader appreciation of its importance have yet to be realized, posing a challenge that requires further investigation.

Obtaining new knowledge and understanding of the conditions that enable effective DfRem will facilitate progress in making this task more accessible to designers. To achieve this, it is crucial to consider the requirements of both the OEM and the designer, a feature that has been missing in many previous developments of DfRem research. It is also essential to avoid overlooking the needs of the remanufacturer. To gain a comprehensive understanding of DfRem in the industry, issues such as design guideline conflicts, prioritization of remanufacturing issues, and OEM-remanufacturer communication, trust, and feedback have been highlighted as areas in need of further investigation. These are just some of the factors to consider when mapping the conditions that enable designers to carry out effective DfRem as part of the design process.

2.4 Future Research

The research within the remanufacturing field is not yet fully complete with this dissertation. There are various topics related to remanufacturing that require further research. Some of the topics that have emerged as areas for further investigation after conducting this research include:

Economic Studies: Conducting more extensive economic studies to determine when and where it is beneficial for a company to initiate a remanufacturing business.

In-Depth Studies on Remanufacturing Companies: Carrying out more detailed and comprehensive studies at remanufacturing companies to obtain a more nuanced and specific understanding of their operations and challenges.

Market Potential Analysis: Performing further analyses to assess the potential size and growth of the remanufacturing sector, including its impact on the broader economy.

Material Sales and Remanufacturing Integration: Investigating how material sales and remanufacturing businesses can be effectively integrated, including exploring the concept of operational sales and its relationship with remanufacturing.

Addressing these research topics would contribute to a deeper and more comprehensive understanding of remanufacturing, its economic viability, and its potential role in various industries.

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