Analysis of Remanufacturer Waste Streams Across Product Sectors

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Abstract
Remanufacture involves the production-batch disassembly, cleaning, repair or replacement of parts, and reassembly of products for reuse. Parts that cannot be reused by the remanufacturer enter the waste stream, examination of which reveals insights about remanufacture difficulties. Extending beyond our previous study of automotive products, the remanufacturer waste streams of electrical motors, toner cartridges, valves and telephones were analysed to support product design that facilitates remanufacture. The results of this research are presented in a format that allows a designer to determine the relevance of the products studied to products being designed.

Keywords: Design, Environment, Remanufacturing

1 INTRODUCTION

The need to consider product end-of-life is motivated in part by current and impending product take-back legislation. While such legislation may impose a burden on manufacturers that arrange for the recycling or disposal of their products, remanufacture provides a potentially profitable end-of-life alternative that may even benefit from take-back legislation. Remanufacturing is often considered as recycling of durable products at a component part level. The used product, or core, is disassembled, cleaned, repaired or refurbished, re-assembled and tested to produce a like-new product. Performed in a batch process, remanufacturing can be an economically and environmentally superior alternative to scrap-material recycling. One requirement, and sometimes burden to remanufacturing, is the procurement of cores to process. Thus, remanufacture may benefit from take-back legislation that facilitates core recovery.

This research aims to support design that facilitates the remanufacture of products. Since the essential goal of remanufacture is to reuse parts, components that are not reused and enter the waste stream of remanufacturers represent the ultimate difficulty in remanufacture. Therefore, the waste streams of the remanufacturers of several product sectors were studied to gain insight into difficulties encountered during product remanufacture. The results of this study are presented in a format that allows the designer to determine the relevance of the products studied to the products being designed.

2 LITERATURE REVIEW

The context of this research in design for remanufacture is environmentally conscious product design and manufacture. An overall approach for environmental assessment of products is Life-Cycle Analysis (LCA) which tracks resource inputs and outputs used for a product from material extraction to end-of-life disposition [1]. While much of the research that addresses product end-of-life is in the area of design for recycling [2], Kimura et al. [3] simulate product quality under deteriorated conditions to support design for reuse and upgrade. Research in design for disassembly aims to facilitate disassembly, typically for recycling, but occasionally also for maintenance and remanufacture [4].

Lund, who began research on the remanufacturing industry in the 1970s, recently completed a survey of the remanufacturing industry in North America, quantifying industry size in terms of sales, number of firms, and types of products remanufactured [5]. With regards to design, guidelines have been published by several sources. VDI, the German Engineers Association, published extensive, but somewhat general, guidelines on designing for end-of-life options including remanufacturing [6]. Researchers at Georgia Institute of Technology developed guidelines and metrics more specific to remanufacture [7].

There remains a paucity of empirically based measures of product remanufacturability. The approach described in this paper is unique in that design for remanufacture will be based on remanufacture difficulties quantified by contributions to remanufacturer waste streams.

3 DATA COLLECTION

Lund identified the top product sectors by number of remanufacturers as automotive aftermarket parts, electrical apparatus (transformers, motors, switch gear), toner cartridges and retreaded tires [5]. Previous work studied the waste stream of automotive remanufacturers [8]. Work described in this paper includes the next two largest product sectors, electrical motors and laser-printer toner cartridges. Two other product sectors with remanufacturers in the Toronto area, valves and telephones, were also studied. Data was grouped into five categories according to similarity in product type and remanufacture process: 1 - toner cartridges at large companies (Toner-Lg), 2 - toner cartridges at small companies (Toner-Sm), 3 - electrical motors (Motors), 4 - telephones (Phones), and 5 - Valves.

Data from large and small toner-cartridge remanufacturers were kept separate due to processing differences. The large company had more automated, assembly-line processes. At the small companies, one operator often performed all processes on a core.

Cores with features that prevent remanufacture are discarded from the remanufacturing process and enter the waste stream. The discarded material, or waste stream, of the remanufacturer is quantified by part count and weight.

Data set sizes for product sectors are shown in Table 1. Each category is analysed to statistically verify that the collected data is representative of the population from which the data was taken. Thus, these results may be generalized within each product group. Statistical analysis found confidence intervals for all discard-reason categories at a 95% confidence level. In the case of confidence intervals that include negative proportions, the sample is deemed to be too small to be significant and is omitted from further consideration.

Data Set Name	Total Part Count [#]	Total Weight [kg]
Toner-Lg	2411	431
Toner-Sm	192	226
Motors	128	11112
Phones	434	41
Valves	425	797

Table 1: Data Set Size by Part Count and Weight.

4 RESULTS AND DISCUSSION

In addition to part count and weight, the reason for discard of each piece of waste sampled was also recorded. As might be expected, many of the discard reasons involve physical damage to the cores. These are grouped as PRODUCT. However, through discussion with the remanufacturing technicians and observation of the process, discard reasons involving the execution of the process are also found. These are called TECHNIQUE. Additionally, the remanufacturers identified issues outside of their control. For example, market changes and legal issues were grouped as OTHER. Lastly, there are cores for which no discard reason could be identified. These are grouped as UNKNOWN.

The discard reasons are the obstacles preventing the core from being remanufactured. From a design perspective, it is useful to identify the condition that allowed the obstacle to occur. This information, the **root cause** of the discard reason, guides designers to avoid problem features in their designs and, further, to incorporate features to promote remanufacturing. Each discard reason is examined to determine a probable root cause. Some root causes are common to all products and are easily generalized to products outside of this study. Other root causes may only be found in one product or data set, however, where it is related to a particular product attribute, it may also be generalized to other products having that attribute. Root causes were grouped into the following four categories: Issues Involving Multiple Influences, Remanufacturing Steps, Working Environment, and Specific Design Features.

4.1 Root Causes Involving Multiple Influences

The first group of root causes involves issues that are influenced by many sources, such that product design may or may not play a role. For example, the effectiveness of core procurement relies heavily on logistics of supply and demand, collection, transportation and storage.

Safety Standards: While in our study, only valves were identified with this root cause, conceivably any piece of safety equipment would be subject to standards. Safety standards dictated that equipment not be used past a certain date, resulting in their discard.

Abuse of Function: Although any product function may be abused, that is, overused, overloaded, etc., in our study, only abuse of motors resulted in damage rendering the product unremanufacturable.

Contamination: In our study, this root cause is specific to toner cartridges and involves toner-powder contamination.

Core Recovery: Core recovery refers to the process of collecting cores from the consumer and transporting them to remanufacturing facilities. There are several issues and stakeholders involved in this process including transportation, distribution, tracking, sorting and economics. Although a product may be designed to facilitate one or more of these, for example, easier identification for sorting, effective and efficient core recovery is still dependent on several other factors. Problems with inappropriate cores were seen in three of the data sets, Toner-Sm, Valves and Phones, where the remanufacturers accepted unspecified cores. In the other two cases, motors were remanufactured on a for-client basis, and the large toner-cartridge remanufacturer ordered cores as needed.

Improper Handling: Product damage occurs due to handling while in use, from customer to dealer to remanufacturer, and back to customer. Although design may alleviate some of the damage occurring through handling, other influences independent of product type, such as education or instructions for correct handling procedure, are also strong contributing factors. All products studied incurred handling damage.

4.2 Root Causes in Remanufacturing Steps

The second group of root causes involves problems with the execution of particular remanufacturing steps, specifically disassembly, assembly and refurbishment. In these cases, the core or component passes the initial inspection and proceeds to the remanufacturing step, but fails to complete the processes for that step.

Long/Difficult Disassembly: Disassembly that takes longer or is more difficult than for most product models, within a product sector, rendered remanufacturing untenable for some motors and valves, the two metal, industrial products in the study. The length of disassembly time affects the ratio of labour cost to resale value.

The presence of this root cause in Toner-Lg refers to damage that results during a difficult disassembly.

No Allowance for Disassembly: When a core is not designed for disassembly with the intention of component reuse, remanufacturers still attempt disassembly, but must use destructive methods such as cutting joints apart. This root cause is only identified for two data sets, Toner-Lg and Phones. It is possible that maintenance requirements for motors and valves ensured that nondestructive disassembly methods were available for these products. The exclusion of this root cause from Toner-Sm indicates that smaller batch sizes and/or individual attention from technicians alleviate some of the problems related to this root cause.

Long/Difficult Assembly: This root cause is similar to Long/Difficult Disassembly.

Special Refurbishment Process: This root cause is specific to Toner-Sm, where there was insufficient production volume to develop and use a roller-recoating process used by the larger toner-cartridge remanufacturer.

4.3 Root Causes in Working Environment

The third group of root causes is related to a damaging condition in the regular working environment of a product. These are conditions that the designer should already be considering in the design.

Cycles of Wet and Dry: This root cause is specific to valves. However, the damage of corrosion may be a consideration for any metal product operating in such conditions. The absence of motors, the other metal product in this study, may be attributed either to better material protection and/or less severe environmental conditions.

Cycles of Low and High Temperature: This root cause affects glue and rubber, which were mainly found in toner cartridges. Similar to the root cause, Delicate Surface, described below, this root cause is product specific to toner cartridges in this study.

Close-Tolerance Relative Motion: Relative motion resulting in wear occurred in all products studied, where some form of relative motion was necessary for product operation.

4.4 Root Causes in Specific Features

The final group of root causes is tied to the damage that occurs to particular design features.

Choice of Light Colour: This root cause is specific to Phones. Discolouration is more of a consideration for plastic than metal products in this study. However, the plastic products studied are used in the home and office, where aesthetic characteristics such as colour may be more important than in industrial environments.

Surface Finish: The root cause surface finish is also common to all plastic products. Toner cartridges have a smooth, shiny surface, and telephones, while not as smooth as toner cartridges, have a fairly uniform surface texture. Scratches in the surface are apparent and detrimental to aesthetic appeal and customer confidence. Although only plastic products in this study were associated with this root cause, the factor likely more important than material type is that consumer products are required to look new. For example, metal components that are visible to consumers would also be likely to have a scratch-free criterion.

Delicate Surface: This root cause is specific to a chemically coated metal component in toner cartridges. Since the root cause appears in both toner-cartridge data sets, size of remanufacturer does not appear to be a factor. Therefore, this root cause is product specific in this study.

Protrusion: Although protrusions are found on all products, this root cause, referring to damage to protrusions, is only significant for Toner-Lg.

Snap-Fits: Snap-fit joints on all plastic products were found to be subject to fractures during disassembly.

4.5 Reference Tables for Designers

The root causes are related to the discard reasons in four tables that correspond to each root-cause group identified above. These tables may serve as reference guides for designers to avoid potential remanufacturing difficulties caused by their product design. In each table, the root causes are in columns, and the discard reasons are rows. The five-sectioned pentagon symbol in the tables (legend in Figure 1) contains the proportion of a product waste stream identified with a particular root cause. Each entry in the table may be read as follows: Problems with <u>column heading</u> causes <u>%</u> of discards in <u>product</u> due to <u>row heading</u>. For example, in Table 5, Column 1: Problems with <u>Choice of Light Colour</u> causes <u>18%</u> of discards in <u>Phones</u> due to <u>Discolouration</u>. Designers would determine the similarity between their products and the ones in this study for applicability of discard reasons and root causes. For example, telephones have a plastic body and are used in the home and office where aesthetics are important. Therefore, discolouration may be a consideration in other plastic products used in the home or office. Also, the proportions of each discard reason may be used to set priorities, keeping in mind the different data set sizes in Table 1. The proportions in Tables 2 to 5 are by part count. Tables by weight were also developed, but are not included here due to space limitations.

Table 2 includes root causes that are influenced by many sources where product design may or may not play a role. As this table involves many different stakeholders, it may contain issues over which designers have the least control.

Table 3 contains root causes involving problems with the execution of particular remanufacturing steps, specifically disassembly, assembly and refurbishment. This table may be used to set goals for the product. For example, identifying the goal that the product must be disassemblable for reuse allows the designer to decide how to accomplish this goal.

Table 4 contains root causes relating to a damaging condition in the regular working environment of a product, which the designer should have already considered. Table 4 may serve to emphasize that some of these existing conditions may also be problematic for remanufacturing.

Table 5 includes root causes tied to the presence of particular design features. This table is specific and prescriptive and is probably the most straightforward to apply. The table indicates where a particular feature causes a particular problem for a particular product.

5 CONCLUSION

Examination of remanufacturer waste streams, coupled with information from remanufacturing technicians, led to empirical evidence of several obstacles to the remanufacturing process. Similar obstacles, or discard reasons, were grouped together. Beyond the identification of remanufacturing discard reasons, their root causes, the conditions that allow the discard reason to occur, were surmised. Identification of root causes provides insight into how to design products to avoid these obstacles to remanufacture.

In order to consolidate the data, the root causes and the discard reasons are cross-indexed in tables. These tables provide a reference for designers to incorporate design for remanufacturing in their existing design methodology. Groups of root causes are presented in separate tables. Similar to the groupings of the discard reasons, there is a group of root causes where product design may not be the main influence. The root causes in the remaining three tables are heavily influenced by product design. These three tables cover remanufacturing process steps, working-environment conditions, and specific product-design features. With this information, designers may be able to avoid obstacles to remanufacturing in their design and facilitate the remanufacturing of their product.

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Figure 1: Legend for Tables 2-5.

DISCARD REASONS \ ROOT CAUSES	Safety Standards	Abuse of Function	Contamination	Core Recovery	Improper Handling
PRODUCT|Burns		41			
PRODUCT|Degradation|Glue			22 2		
PRODUCT|Degradation|Photo-Sensitive Material					2
PRODUCT|Fracture|Other					1 4 4 24* 9
PRODUCT|Fracture|Non-Deformation Joint					1
PRODUCT|Yielding|Dent					8 1
TECHNIQUE|Cleaning|Contamination			7		
OTHER|Legal Issue	18				
OTHER|Not Common				5	
OTHER|Overstock				4 1	

* CRACKS AT SEAM LINES AND EDGES VS WITHIN THE BODY WERE NOT RECORDED SEPARATELY. THIS PERCENTAGE INCLUDES BOTH TYPES OF FRACTURES.

Table 2: Root Causes Involving Multiple Influences.

DISCARD REASONS \ ROOT CAUSES	Long/ Difficult Disassembly	No Allowance for Disassembly	Long/ Difficult Assembly	Special Refurbishment Process
PRODUCT|Degradation|Photo-Sensitive Material				2
PRODUCT|Degradation|Rubber				10
PRODUCT|Fracture|Other		24*		
PRODUCT|Fracture|Deformation Joint	3			
PRODUCT|Fracture|Non-Deformation Joint		5		
PRODUCT|Wear	2			15
PRODUCT|Yielding|Scratch				5
TECHNIQUE|Disassembly|Label		3 1		
TECHNIQUE|Disassembly|Model Change		8		
TECHNIQUE|Disassembly|Sacrificial		19		
OTHER|Labour|Sales	3 6		3 6	

* THE NUMBER OF CRACKS AT SEAM LINES AND EDGES VS WITHIN THE BODY WERE NOT RECORDED. THIS PERCENTAGE IS THE MAXIMUM POSSIBLE PERCENTAGE.

Table 3: Root Causes in Remanufacturing Steps.

DISCARD REASONS \ ROOT CAUSES	Cycles of Wet and Dry	Cycles of Low and High Temperature	Close Tolerance, Relative Motion
PRODUCT|Degradation|Corrosion	27		
PRODUCT|Degradation|Glue		22 2	
PRODUCT|Degradation|Rubber		<1 10	
PRODUCT|Wear			7 15 1 6 33

Table 4: Root Causes in Working Environment.

DISCARD REASONS \ ROOT CAUSES	Choice of Light Colour	Surface Finish	Delicate Surface	Protrusions	Snap-fits
PRODUCT|Degradation|Discolouration	18				
PRODUCT|Yielding|Scratch		1 3 16	7 2		
PRODUCT|Fracture|Deformation Joint					3 3 4
PRODUCT|Fracture|Protrusion				6	
PRODUCT|Fracture|Non-Deformation Joint				2	

Table 5: Root Causes in Specific Features.