

ANALYSIS OF REMANUFACTURER WASTE STREAMS FOR ELECTRONIC PRODUCTS

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Abstract

The long-term goal of this work is to enable design of durable products that facilitates remanufacture. Remanufacturing, or recycling at a part level, involves the production-batch disassembly, restoration to like-new condition and reassembly of used products. Remanufacturing offers significant environmental benefits by retaining the energy, as well as material, embodied in the product during original manufacture, while diverting solid waste from landfills. Since the essential goal of remanufacture is to reuse parts, parts that are not reused enter the waste streams of remanufacturers and represent the ultimate obstacles to remanufacture. Study of these waste streams reveals insights about difficulties in remanufacture and how to avoid these difficulties through product design.

Traditionally, remanufacturing has centered on products such as automotive parts and electrical motors. However, the growth in electronic and electrical product sectors has triggered a corresponding growth in the remanufacturing in these sectors. To support design for remanufacture in these sectors, waste streams of remanufacturers of different electronic products, namely laser-printer toner cartridges and telephones, were studied and quantified. This paper presents the results of these waste-stream analyses, including the identification of discard reasons, associated root causes for these discard reasons, and consequently, product design and other characteristics that are problematic for remanufacturing.

I. INTRODUCTION

Environmental concerns as well as increasing take-back legislation in Europe and Asia are motivating consideration of product end-of-life options other than landfill and incineration. Remanufacturing can be an economically and environmentally superior end-of-life alternative to material recycling. Remanufacturing is a production-batch process where used products, or cores, are disassembled, cleaned, repaired or refurbished, reassembled and tested to produce like-new products. Since the essential goal of remanufacture is to reuse parts, parts that are not reused enter the waste streams of remanufacturers and embody the ultimate obstacles to remanufacture. Therefore, to support design for remanufacture, the waste streams of remanufacturers were studied.

Traditionally, remanufacturing has centered on products such as automotive parts and electrical motors. However, the growth in electronic and electrical product sectors triggered a corresponding growth in the remanufacturing in these sectors. This paper describes the research results of waste-stream analyses on two such products, laser-printer toner cartridges and telephones. Presented are the discard reasons identified, associated root causes for these discard reasons, and consequently, product design and other characteristics that are problematic for remanufacturing.

II. LITERATURE REVIEW

The body of literature related to remanufacturing is diverse. Lund (1984) [1] and Overby (1980) [2] both extolled the benefits of material and energy conservation, job creation, pollution reduction, and reduction of waste offered by remanufacturing. More recently, Lund (1996) completed a quantitative survey of the remanufacturing industry in North America [3].

Relevant design guidelines have also been published. The German Engineers Association (VDI) published extensive, somewhat general, guidelines on designing for various end-of-life options including remanufacturing [4]. More specific guidelines from Georgia Institute of Technology [5], [6], [7] include a selection table for fasteners and remanufacturability metrics.

In industry, Xerox is one of the most often-cited examples of remanufacturing practice, where cores, particularly used photocopiers to be remanufactured, are recovered at the end of lease. Design guidelines and standards at Xerox include those that aim to minimize the environmental impact of their products. For example, the following practices were advocated: use common materials to aid recycling, replace paper with plastic to facilitate reuse [8], and use assembly methods suitable for future disassembly [9].

IBM established a facility in Endicott, NY as a reutilization and demanufacturing center that performs activities such as disassembly for parts reuse. This facility works with IBM's Engineering Center for Environmentally Conscious Products to close the design loop regarding disassembly techniques, problems or concerns [10]. Reported were both positive and some negative results from changes in product designs [11].

Other companies reporting on their voluntary take-back systems are UNISYS [12] and Hewlett-Packard (HP) [13]. These companies described reverse distribution in the form of free shipping and/or cash credit for returned cores. HP commented on the connection between design influences and disassembly times.

Despite the large body of related work, there is sparse research regarding the quantitative connection between the product's design and the success of remanufacturing that product. The research of the Life-Cycle Design Laboratory at the University of Toronto is aimed at this gap in research knowledge. The research undertaken quantifies the amount of product discarded (as opposed to reused) and categorizes discard reasons that impede remanufacturing. From the discard reasons, it is possible to identify engineering design choices that directly affect the remanufacturability of the product through contribution to the waste stream.

The literature from industry demonstrates the presence of in-depth knowledge of a particular product, line of products, or industry. Even though some of the knowledge may be product or industry specific, much of the insight may be transferable, thus enabling overall comparisons. With this in mind, a data collection procedure was formulated.

III. PROCEDURE

Cores with product design features that prevent remanufacturing are discarded and enter the waste streams of remanufacturers. Identification of discard reasons and quantification by weight and part-count contribution resulted from the study of these waste streams. From the top four product groups in the remanufacturing industry, including automotive parts, electrical motors, and tires [3], laser-printer toner cartridges were chosen for this study. Other research by the Life-Cycle Design Laboratory focused on automotive products [14]. Also included here is data collected from a local remanufacturer of telephones. Three data sets are presented: toner cartridges from a large company (toner-lg) as well as small companies (toner-sm), and telephones (phones).

At each company, the owner or operator was contacted to assess company receptiveness to research. Before beginning data collection, an

orientation by a senior technician or supervisor was given and examples of discard reasons were shown. As data collecting progressed, employees were available for questions. Both weight and part count were used to quantify the waste stream.

A. Company Differences

The large company (toner-lg) processes different cartridge models in separate assembly lines due to high production volume. The small companies (toner-sm, phones) generally have a set of technicians who can work on any model as required.

The large company is able to control the process input to a greater degree than the small companies. The large company uses mostly cartridges that were used only once before and never remanufactured. The small companies studied have to contend with more uncertainty in origin and quality of cores.

B. Process Similarities

In all cases, the remanufacturing process of a core is very similar. Cores are first received and inspected for irreparable damage. Then, suitable cores are disassembled, cleaned, repaired (including part replacement and/or refurbishment), assembled, and tested. With telephones, the cores may also be subject to a performance check prior to disassembly.

C. Data Collection Methodology

Waste is typically discarded at specific areas, usually at or near the technician's work area. The technician who disassembles or assembles the product verbally explains the decision to discard certain parts. The discard reason or thought process is recorded, and the parts are counted and weighed. If there is more than one discard reason for a part, all reasons are recorded for that part.

The large company generates enough waste on any given day for data collection. Visits were made once a week over several months. The small companies stored their waste for two or three days before a visit. Each of the small companies was visited once a week for a minimum of three weeks.

IV. RESULTS AND DISCUSSION

All discard reasons are categorized under four groups. Discard reasons involving physical damage to the cores are grouped as PRODUCT. Through discussion with the remanufacturing technicians and observation of the remanufacturing process, discard reasons involving the execution of the remanufacturing process are also found. These discard reasons are called TECHNIQUE. Also, the remanufacturers identified issues outside of their control such as core recovery. These issues are grouped as OTHER. Lastly, there are cores for which no discard reason could be identified. These cases are grouped under UNKNOWN.

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

Data-Set Name	Total Part Count [#]	Total Weight [kg]
Toner-Lg	2411	431
Toner-Sm	192	226
Phones	434	41

Table 1 shows sizes of the different data sets. The percentage of each discard reason in each data set was analyzed to statistically verify that the collected data is representative of the population from which the data was taken. Statistical analysis found confidence intervals for all percentages at a 95% confidence level. Thus, these results may be generalized within each product group. In the case of confidence intervals that include negative percentages, the sample is deemed to be too small to be significant. These cases are not included in the discussion.

The **discard reasons** listed in Section A below are the obstacles that prevent the core from being remanufactured. From a design perspective, it is useful to identify the condition that allows the obstacle to occur. This information, the **root cause** of the discard reason, allows designers to avoid problem features in design and, further, to incorporate features to promote remanufacturing. Each discard reason is examined to determine a probable root cause. While not all discard reasons could be matched with a root cause, some root causes are common to all products and can be reasonably 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. Table 2 shows sample product attributes for the products studied. Each root cause is reviewed in Section B.

A. Discard Reasons:

1) PRODUCT

- Burns: accidental, not related to function or remanufacturing process. No Root Cause assigned.
- Degradation (Discoloration): occurs in light-colored plastic products. An aesthetic issue.
- Degradation (Glue): occurs in seals.
- Degradation (Photo-Sensitive Material): material in toner cartridges unnecessarily exposed during remanufacturing.
- Degradation (Rubber): specific to toner cartridges.
- Fracture (Deformation Joint): mainly snap-fits.

Table 2. Sample Product Attributes.

Attribute	Telephones	Toner Cartridges
In-use Exposure to Heat	No	Yes
Electronic Parts	Yes	No
Color	Various	Black

- Fracture (Non-Deformation Joint): joints such as those that are pinned or glued.
 - Fracture (Other): cracks in the body, not near a stress intensifier.
 - Fracture (Protrusion): refers to protrusions that are not part of a joint.
 - Wear: occurs were relative motion is involved.
 - Yielding (Bend): overall part deformation. No Root Cause assigned.
 - Yielding (Dents): local part deformation.
 - Yielding (Scratches): both an aesthetic and a functional issue. Also affects customer confidence.
- 2) TECHNIQUE
- Cleaning (Contamination): toner-cartridge specific.
 - Disassembly (Labels): involves trademark issues.
 - Disassembly (Model Change): one toner-cartridge model not suitable for assembly line processing.
 - Disassembly (Sacrificial): material sacrificed to enable destructive disassembly.
- 3) OTHER
- Not common: uncommon product model.
 - Overstock: shortage of storage space for readily available items.
- 4) UNKNOWN
- Missing Part: no Root Cause assigned.
 - No Reason: no Root Cause assigned.
 - Performance Test: decision to discard based on performance; underlying discard reason not investigated. No Root Cause assigned.
 - Visual Check: decision to discard based on visual cues; underlying discard reason not investigated. No Root Cause assigned.

B. Root Causes:

Choice of Light Color: This root cause is specific to phones. Discoloration may be a consideration for any plastic item, but is not seen in toner cartridges due to their uniform black color. Telephones are visible during use, thereby requiring stringent aesthetic standards.

Surface Finish: This root cause is common to both 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 easily apparent and detrimental to aesthetics and customer confidence. While toner cartridges are not in plain view during use, many consumers expect a product that is scratch-free and otherwise looks new when the cartridge is unpacked from the box.

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

Protrusion: Although fracture of protrusions is found in all data sets, the sample size for this root

cause is only significant for toner-1g. The sample sizes at all other remanufacturers did not produce significant percentages. Generally, all protrusions are susceptible to fracture.

Snap-Fits: Snap-fit joints on both products were subject to fractures. Although snap-fits are a common fastening method recommended for easier assembly and recycling, they are prone to fracture, particularly during disassembly.

Contamination: This root cause is specific to toner cartridges. When the seals that contain toner powder within the cartridge fail, the powder invades the entire product, is extremely difficult to completely remove, and renders the cartridge unusable.

Core Recovery: Core recovery refers to the collection of cores from consumers and transportation to remanufacturing facilities. Several issues involved in this process include transportation, distribution facilities, tracking, sorting and economics. While a product may be designed to facilitate one or more of these, for example, easier identification for sorting, effective and efficient core recovery still depends on several other factors. Core recovery may affect any product.

Handling: Handling occurs during use and transportation from customer to dealer to remanufacturer and back to customer. Although design may alleviate some of the damage occurring through handling (such as allowing for better packaging to reduce fractures), other influences independent of product type, such as education or instructions for correct handling procedure, are also strong contributing factors. Thus, all types of products are affected by handling damage.

Long/Difficult Disassembly: Difficult disassembly resulted in damage to screw heads in toner-1g. Screwdriver torque is specified by the remanufacturer to avoid damaging the plastic threads of the housing. Damage to the housing threads might lead to improper assembly, which is harder to detect than damage to screw heads. Therefore, the damage to screws is preferable even though such damage also renders the housing unusable.

No Allowance for Disassembly: When a core is not designed for disassembly with the intention of component reuse, remanufacturers still try to disassemble it, but must use destructive methods such as cutting joints that occasionally result in damage. This root cause is only a concern for toner-1g and phones. The exclusion from data set toner-sm suggests that smaller batch sizes and/or individual attention from technicians alleviate some problems related to this root cause for certain products.

Special Refurbishment Process: This root cause is specific to toner-sm. Certain coated components in toner cartridges may be recoated when necessary.

While recoating is a known refurbishment technique in the toner-cartridge remanufacturing industry, this process is frequently too expensive for a small remanufacturing company with smaller production volumes.

Cycles of High and Low Temperature: This root cause degrades glue and rubber, mainly found in toner cartridges. This root cause is product specific to toner cartridges in this study.

Close-Tolerance Relative Motion: Wear resulting from relative motion occurred in all products studied. Any product that requires relative motion for operation may be subject to wear.

C. Reference Tables for Designers

The root causes are cross-indexed with the related discard reasons to form reference tables for designers. The tables may be used to avoid potential remanufacturing problems in future product design. In each table, the root causes form the columns, and the discard reasons form the rows. Figure 1 contains the product legend used for the three-section symbol in Tables 3 to 6. This symbol contains the corresponding proportion of the corresponding product's waste stream. Each entry in the table may be read as follows: "Problems with column heading causes % of discards in product due to row heading." For example, Table 3, Column 1: Problems with Choice of Light Color causes 18% of discards in Phones due to Discoloration. Designers must determine the similarity between their product and the ones in this study to judge applicability of the root cause. In the above example, telephones have a plastic body and are used in the home and office where aesthetics are important. Aesthetic defects may be more acceptable on industrial products. Also, the proportions of each discard reason can be used to set priorities, keeping in mind the different data-set sizes in Table 1. Tables by part count are shown; tables by weight were also formulated, but are not shown here.

Four groups of root causes are identified as Specific Design Features, Multiple Influences, Remanufacturing Steps, and Working Environment Conditions. Each root-cause group is contained in a corresponding table.

Table 3 includes root causes that are tied to the presence of a particular design feature. This table is specific, prescriptive and likely the most straightforward for a designer to apply. It specifies that a particular feature causes a particular problem for a particular product. Features range from Choice of Light Color to Snap-Fits.

Table 4 shows root causes that have multiple influences, where product design may or may not play a significant role. For example, Core Recovery relies heavily on logistics of supply and demand, collection, transportation, and storage. Since the root

causes, Contamination, Core Recovery and Handling, involve many stakeholders, the effect of design on these root causes may be the least straightforward.

Table 5 contains root causes involving problems with the execution of a remanufacturing step, specifically disassembly and refurbishment. In these cases, the core or component passes the initial inspection and proceeds to the remanufacturing step, but fails to complete the step. This table may be used to set goals for the product. For example, 'product must disassemble for reuse', leaves the designer the freedom to modify the design to accomplish this goal. Included in this table are root causes of Long/Difficult Disassembly, No Allowance for Disassembly and Special Refurbishment Process.

Table 6 contains all root causes relating to a damaging condition in the product's regular working environment. These are existing conditions for which the designer should already be considering in the design. This table may serve to emphasize that some of these existing conditions may also be remanufacturing problems. Included are root causes of Cycles of Low and High Temperature and Close-Tolerance Relative Motion.

V. CONCLUSION

Examination of remanufacturers' waste streams, coupled with information from remanufacturing technicians, led to empirical evidence of several obstacles to the remanufacturing process. Similar obstacles are grouped together. Beyond the identification of remanufacturing discard reasons, their root causes, the conditions that allow the discard reason to occur, were surmised. Root causes are useful for understanding how to design a product to avoid these obstacles.

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. Root causes are grouped and categories of root causes are shown in separate tables. There is one category of root causes where product design may not have significant influence. The root causes in the remaining three categories are heavily influenced by product design, and include remanufacturing process steps, working-environmental conditions, and specific product-design features. With this information, designers may be able to incorporate design for remanufacturing in their existing design methodologies whether they are designing a new product or redesigning an existing product.

VI. REFERENCES

1. Lund, R.T., 1984, Remanufacturing, *Technology Review*, 87/2:19-29.

2. Overby, C.M., 1980, Product recycling (remanufacturing) as a conservation option: An international dimension. In *Advances in materials technology in the Americas - 1980, Vol. 1 - Materials recovery and utilization*. pp. 113-119.
3. Lund, R.T., 1996, *The Remanufacturing Industry: Hidden Giant*, Boston, MA: Boston University.
4. VDI (Association of German Engineers) 1991, *Guidelines for designing technical products for ease of recycling: Fundamentals and rules for design*, Dusseldorf.
5. Hammond, R.C., 1996, *The development of design metrics for remanufacturing*, M.S. Thesis, Georgia Institute of Technology, Atlanta.
6. Amezcua, T., Hammond, R., Bras, B., 1995, Design for Remanufacturing, *Int. Conference on Engineering Design: ICED 95*, Praha.
7. VerGow, Z., Bras, B., 1994, Recycling oriented fasteners: A critical evaluation of VDI 2243's selection table, *Advances in Design Automation*, 2:341-349.
8. Farkash, R., Mueller, K., 1995, The evolution of environmental initiatives for toner containers at Xerox Corporation, *IEEE Int. Symp. on Electronics & Environment*, Orlando, Florida, May 1-3, pp. 267-272.
9. Seaver, W.B., 1994, Design considerations for remanufacturability, recyclability and reusability of user interface modules, *IEEE Int. Symp. on Electronics & Environment*, San Francisco, California, May 2-4, pp. 241-245.
10. Grenchus, E., Keene, R., Nobs, C., 1997, Demanufacturing of information technology equipment, *IEEE Int. Symp. on Electronics & Environment*, San Francisco, CA, May 5-7, pp. 157-160.
11. Dunnett, M., Grenchus, E., Keene, R., Yehle, L., Jacques, M., Karlsson, M., Kirby, J.R., Pitts, D., 1999, Evaluation of IBM end of life products: Measuring DfE effectiveness, *IEEE Int. Symp. on Electronics & Environment*, Danvers, MA, May 11-13, pp. 98-103.
12. Bartel, T., 1995, Recycling program for printer toner cartridges and optical photoconductors, *IEEE Int. Symp. on Electronics & Environment*, Orlando, Florida, May 1-3, pp. 225-228.
13. McGavis, D., 1994, The Energy bucket and a not-so-drop-in-the-bucket portion of the waste stream, consumables, *IEEE Int. Symp. on Electronics & Environment*, San Francisco, CA, May 2-4, pp. 267-272.
14. Sherwood, M., Shu, L., 2000, Supporting design for remanufacture through waste-stream analysis of automotive remanufacturers, *CIRP Annals*, 49/1:87-90.

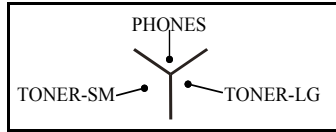


Figure 1. Legend for Tables 3-6 Indicating Percentage of Product Waste Stream.

Table 3. Specific Design Features.

		ROOT CAUSES				
		Choice of Light Colour	Surface Finish	Delicate Surface	Protrusions	Snap-fits
D I S C A R D R E A S O N S	PRODUCT Degradation Discolouration	18				
	PRODUCT Yielding Scratches		16 3 1	2 7		
	PRODUCT Fractures Deformation Joints					4 3 3
	PRODUCT Fracture Protrusion				6	
	PRODUCT Fracture Non-Deformation Joint				2	

Table 4. Multiple Influences.

		ROOT CAUSES		
		Contamination	Core Recovery	Handling
D I S C A R D R E A S O N S	PRODUCT Degradation Glue	2 22		
	PRODUCT Degradation Photo-Sensitive Material			2
	PRODUCT Fracture Other			24* 4 1
	PRODUCT Fracture Non-Deformation Joint			1
	PRODUCT Yielding Dent			1
	TECHNIQUE Cleaning Contamination	7		
	OTHER Not Common		5	
OTHER Overstock		1		

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

Table 5. Remanufacturing Steps.

		ROOT CAUSES		
		Long/Difficult Disassembly	No Allowance for Disassembly	Special Refurbishment Process
D I S C A R D R E A S O N S	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 Labels		1 3	
	TECHNIQUE Disassembly Model Change		8	
	TECHNIQUE Disassembly Sacrificial		19	

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

Table 6. Working Environment Conditions.

		ROOT CAUSES	
		Cycles of High and Low Temperature	Close Tolerance, Relative Motion
D I S C A R D R E A S O N S	PRODUCT Degradation Glue	2 22	
	PRODUCT Degradation Rubber	10 <1	
	PRODUCT Wear		6 15 7